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MECHANICAL ENGINEERING

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JOHN W. BLODGETT

(Excerpt from Reforestation and Timber Supply, p. 59)

FEBRUARY 1924

THE MONTHLY JOURNAL PUBLISHED BY THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS

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Mechanical Engineering

The Monthly Journal Published by

The American Society of Mechanical Engineers

Publication Office, 207 Church Street, Easton, Pa. Editorial and Advertising Departments at the Headquarters of the Society, 29 West Thirty-ninth Street, New York

Volume 46 February, 1924 Number 2

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Price 60 Cents a Copy, $5.00 a year: to Members and Affiliates, 50 cents a Copy, $4.00 a year. Postage to Canada, 75 Cents Additional; to Foreign Countries $1.50 Additional. Changes of address should be sent to the Society Headquarters.

Entered as second-class matter at the Post Office at Easton, Pa., under the Act of March 3, 1879.
Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized on January 17, 1921.

J. W. Blodgett

F. G. Tryon

W. F. McKenney

N. S. Osborne

Contributors to this Issue

John W. Blodgett who writes on Reforestation and Timber Conservation, has been associated with lumbering since his birth. His father settled as a pioneer on the Muskegon River, near Hersey, Michigan, in 1847. The son knew the virgin white-pine forest, saw it gradually disappear as the Michigan lumber mills climbed to their zenith, during years when half a billion feet of logs were floated down the Muskegon River, and finally witnessed the decline of the industry to its ultimate extinction. These associations begun in Michigan have extended and now embrace many large operations in the extensive lumber fields of the South and West. He has devoted many years to conserving the present timber stands and to developing practical reforestation policies, and the experience gained during this period has convinced him that the denuding of forest lands with no constructive plan for perpetuating their growth is a crime against national economics.

As president of the National Lumber Manufacturers' Association and chairman of the central committee on lumber standards, Mr. Blodgett has had broad contacts with all phases of the subject and his constructive analysis of the problem is based on a lifelong acquaintance with lumbering.

* * * * *

H. A. Stevens Howarth, author of the paper in this issue on A Graphical Study of Journal Lubrication, is general manager and chief engineer of the Kingsbury Machine Works, Philadelphia, Pa. Mr. Howarth was born in New Haven, Conn. He was graduated from Yale University in 1899 with honors in mechanical engineering. Several years of practical experience with steel mills and manufacturing were followed by instructing in mechanical engineering at Lehigh University and the Carnegie Institute of Technology. He has been associated with the Kingsbury Machine Works for the past ten years.

Mr. Howarth became a member of the A.S.M.E. in 1908, and served as the Society's representative on the Advisory Board cooperating with the Federal Petroleum Specifications Committee. He is also a member of the American Society for Testing Materials. He has published numerous analytical articles on practical subjects.

F. G. Tryon and **W. F. McKenney,** coauthors of the paper on Economic Phases of Coal Storage, are both associated with the United States Geological Survey. Mr. Tryon has been for the last four years geologist in charge of coal and coke statistics in the Division of Mineral Resources. He is a graduate of the University of Minnesota, where he studied economics and mining geology. During the War he served in the statistical department of the War Industries Board and the General Staff. From October, 1922 to September, 1923, Mr. Tryon acted as statistical adviser to the U. S. Coal Commission.

Mr. McKenney, before joining the Survey in 1920, was special field agent for the Bureau of Labor Statistics and had charge of the field collection of the Bureau's data on employment, wages and earnings of coal miners. He is at present in charge of the Geological Survey's weekly report on the production of coal and coke, and jointly with Mr. Tryon has prepared a number of reports on special studies published by the Survey and others.

* * * * *

C. W. E. Clarke, power engineer with Dwight P. Robinson & Co., New York City, contributes a paper on Boiler-Test Results with Preheated Air. Mr. Clarke's early associations were in Chicago where he designed several power and refrigerating plants for Armour & Co. Later as chief draftsman for Sargent & Lundy, the design specifications and construction work for installations aggregating 100,000 kw. in the Chicago district were completed under his direction. In 1907 he became associated with the New York Central Lines and was in charge of mechanical engineering in the New York electrical zone until 1910. Between that time and the time of his joining Dwight P. Robinson & Co., Mr. Clarke was connected with the firm of Stone & Webster.

Nathan S. Osborne, whose paper on A Calorimetric Method of Surveying the Behavior of Steam is included in this issue, was graduated from the Michigan College of Mines with the class of 1899. He spent about one year in engineering work and then returned to the college as an instructor in mathematics and physics. In 1903 he entered the service of the Bureau of Standards, where his activities for the greater part have been directed to research. He has contributed to tables of thermal properties of ammonia in a series of calorimetric investigations. At present Mr. Osborne is detailed as research associate to the Bureau of Standards by The American Society of Mechanical Engineers, and is conducting the research in progress at that Bureau on the thermal properties of steam.

* * * * *

On June 23, 1921, a group of scientists and engineers met in Cambridge, Mass., and discussed the available information on the properties of steam. As a result of this conference a program of research was planned. The A.S.M.E. was requested to sponsor it and the raising of funds was commenced under a subcommittee of its Research Committee. Work was started very soon both at Harvard and M.I.T. and later, part of the program was taken up by the Bureau of Standards.

In this issue of Mechanical Engineering there is an extensive report of progress at the three institutions. The Bureau of Standards and M.I.T. are well along in the construction of their apparatus and at Harvard, at which some work had been done previous to the preparation of this program, some experimental results have been attained. The objective is, of course, steam tables which will be accurate in the upper ranges of temperatures and pressure.

Cleveland Spring Meeting

May 26–29, 1924

The technical program for the Cleveland Meeting is well under way. Members who are planning to submit papers should advise the Secretary of the Society at once. Papers must be in the hands of the Committee on Meetings and Program by March 15.

MECHANICAL ENGINEERING

Volume 46 February, 1924 No. 2

Reforestation and Timber Conservation

Nation-Wide Reforestation Policy a Necessity—Federal Government Well Equipped to deal with Problem—Duty of Engineers to Prolong Existing Timber Supply Through Closer and Better Utilization of the Product

By JOHN W. BLODGETT,[1] GRAND RAPIDS, MICH.

THE PROBLEM of reforestation in order to maintain a perpetual timber supply for the people of the United States is one whose solution is perhaps as urgent as any that confronts this country today. While dealing as it does with the continuous supply of a commodity whose use is universal, and which enters into every field of our commercial, industrial, and even social existence, it is, strange to say, one of the least clamorous.

The danger of neglecting it is an insidious one, and lies in the fact that there is little in today's conditions to cause present inconvenience or alarm. The actual demands for lumber and paper are being fully met, and there are few indeed who realize the urgent necessity for early action, because of the many years required to grow a new crop of timber.

The members of this Society associated as they are with practically every branch of industry, can and should be a very potent influence in this matter of reforestation. You stand in the public eye as men of vision, but also as men who deal in facts and not in fancies. I feel that no body of men can wield a wider influence, because your conclusions are known to be those of trained minds, and as a profession you are entirely disassociated from any suggestions of political propaganda or of selfish interest.

On behalf of the lumber-manufacturing industry of the United States, permit me to voice its appreciation of the recognition expressed through this invitation to appear before you today. At the same time I want to explain that there has been no opportunity to present my views on reforestation to the authorized representatives of our industry, and I have, therefore, no warrant to speak for it on this subject. Whatever views and conclusions I may present to you today must be judged solely on their merits, and not as representing the composite view of the industry to which I belong.

Photo by U. S. Forest Service

FIG. 1 FIRE-PATROL STATION
(Note man on tree top under flag.)

THE NECESSITY OF ADOPTING A NATION-WIDE REFORESTATION POLICY

The Department of Agriculture, through its bureau of forestry, states that the total annual drain upon our forest reserves is about four times the rate of replacement, and that the yearly drain in merchantable saw timber is about six times the rate of replacement. It follows, therefore, that a practical nation-wide reforestation policy must be adopted in the United States or future generations will face a timber famine. Indeed, our highest authority on this subject, the Forest Service, believes that there will be an unavoidable hiatus between the exhaustion of the present timber supply and the maturing of a new crop.

The Secretary of Agriculture, testifying recently before a Senate Committee on Reforestation, stated to this committee that we had in the continental United States approximately 469,000,000 acres of forest lands, including both cut and uncut. The Secretary further stated that if this great area could be made to produce wood steadily, a yearly crop of from twenty-five to thirty billion cubic feet could be obtained, or roughly twenty per cent more than the present consumption. As timber grows scarcer and more remote its products advance in price and the per capita consumption ofttimes declines, but with the inevitable increase of population it can be seen that the provision suggested by the Secretary of Agriculture is quite conservative.

Of this 469,000,000 acres the Secretary stated that about 150,000,000 acres, or practically thirty-two per cent, are in farm wood lots, and 138,000,000 acres, or more than twenty-nine per cent, are in virgin forests. This leaves, therefore, 181,000,000 acres of cut-over lands, which are either barren or in various stages of reforestation. This area of cut-over lands is being added to at the rate of perhaps four millions of acres annually, and definite plans must be adopted to make and keep it productive.

There are only three agencies through which, either singly or in coöperation, this land can be reforested: namely,

a Private Enterprise
b State Governments
c The Federal Government.

In order to intelligently consider the problem we must divide it into two classes:

a Reforestation for the purpose of producing timber chiefly for wood pulp and low-grade material, such as crating lumber, etc.
b Reforestation for the purpose of producing timber which will make lumber suitable for essential purposes.

[1] President, National Lumber Manufacturers Association.

Address at the Forest Products Session, Annual Meeting of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS, New York, December 7 to 6, 1923.

By essential purposes I mean lumber for railway track and car material, for agricultural implements, for motor-vehicle bodies, for factory construction work, house building, furniture, airplanes, and for the multitude of stress purposes requiring strong, close-grained old-growth wood.

REGROWTH OF TIMBER FOR PULPWOOD AND LOW-GRADE MATERIAL

In considering the regrowth of timber for the first purpose, i.e., pulpwood, etc., we know that it can be reproduced in from twenty to forty years, according to the location and the species of timber involved. With exemption from the annual property tax and the substitution therefor of a yield tax, to be paid as and when the timber is harvested, this kind of reforestation may offer a reasonable opportunity for private enterprise. Unfortunately, however, the constitutions of many of the states inhibit any exemption of growing timber from the annual property tax. Wherever this unfortunate condition exists it should be at once changed by proper constitutional amendment. This is a matter which well deserves the active support of all the engineering societies which are housed in this magnificent building. There are some instances where corporations having heavy investments in pulp and paper plants have purchased large areas of land and are reforesting to provide reservoirs of future timber supplies. It is, however, only the strongest financially that can afford to tie up the capital necessarily involved in this kind of investment. Given adequate fire protection there will be large areas of regrowth timber in smaller miscellaneous ownerships, which will greatly augment the supply of pulpwood. In my own state, Michigan, all the privately owned second-growth timber which survives is cut for this purpose as soon as it reaches a suitable size, and I have no doubt the same condition prevails in other states in which pulp and paper mills are located. Private enterprise, then, as applied to regrowth of pulpwood timber, needs adequate fire protection and a reasonable method of taxing young timber growth.

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FIG. 2 SPROUTS APPEAR AROUND STUMPS VERY SOON AFTER CUTTING
(Two years after cutting.)

So far as the timber from the state-owned forests is concerned, it is the general policy of the states to hold it until it is suitable for lumber, and therefore only the smaller growth, which is thinned out in good forestry practice, would be cut for pulpwood or crating. The Federal Government follows the same general policy, and consequently not very material help can be expected from either source except in the remote possibility of a paper shortage.

The states, however, can coöperate by taking early action regarding both better fire protection and a better form of taxation. To promote and hasten these results the influence of the engineering profession can be a most effective agency.

Pulpwood can be so quickly reproduced that an actual crisis can and should be foreseen in time to avert it. It may be that individual enterprise, under favorable conditions, will nearly or quite solve the problem of insuring us a continuous supply of paper. Let us then remove the obstacles, give the forest-land owner a fair chance, and see how far private reforestation will go.

REGROWTH OF TIMBER SUITABLE FOR LUMBER

When we approach the second class of reforestation, i.e., regrowth of timber suitable for lumber, we face a different and more difficult situation. Our first agency, i.e., private enterprise, must be excluded as an adequate possibility in this direction, because it requires practically a century to mature timber that would yield lumber suitable for stress purposes. No individual will embark in a business from which only his grandchildren can hope to realize results. Occasionally there will be found a man with a long purse, and a large and favorably located tract of land fitted only for tree culture, and whose hobby is reforestation, who is spending his time and money in an attempt to demonstrate that reforestation as a private enterprise is practicable. We all know, however, that these few men, patriotic as they are, stand alone and have never been able to convince the great body of land owners. Generally speaking, even under the best conditions, private reforestation will mean not lumber but wood pulp.

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FIG. 3 AT FIVE YEARS OF AGE THE SPROUTS ARE WELL UNDER WAY
(For comparison note man in middle foreground.)

This brings us to the consideration of the second agency: the states as a possible avenue for this type of reforestation. Forestry has been practiced by some of the states since about 1900, though the majority began some years later. The total appropriation by the states for strictly reforestation work in the year 1921 was $188,702. This does not include appropriations made for fire protection, but is supposed to include all money expended in nursery work, reforestation, and the purchase of additional lands. I have not obtained the figures showing the total area of state-reforested lands, but the result in Michigan, which has been working since 1904, and which is as forward looking as the majority of states, will serve as an example of what we may expect from state reforestation. Michigan in the nine years following 1904 expended for reforestation and nursery purposes $12,722 and reforested 1748 acres. I have not been able to learn the amount used for this purpose since 1913, but know that it was not appreciably larger. The total acreage now under Michigan forestry management is about 180,000, out of nearly five million acres suited for this purpose only. Of this 180,000 acres about 12,000 have been reforested by some planting, part of the balance is in various states of natural reforestation, and some of it utterly barren as the result of repeated burnings. This, then, is the result of nineteen years of state reforestation in a state where timber grows naturally and where there are millions of acres unfitted for any other use, yet probably few states make a much better showing.

Our states are now generally burdened with debt as the result of extensive road building, and many of them have also made large bond issues for soldiers' bonuses. Taxes are mounting so fast that few of the timber-growing states are appropriating anywhere

near enough money to provide fire protection, and it is clearly hopeless to expect them to appropriate funds for the purpose of buying large areas for reforestation. Most of them cannot issue bonds for such a cause owing to the restrictions in their constitutions, and in view of the large indebtedness they carry any attempt to amend the constitutions for this purpose would fail. The net results of state reforestation today show clearly that for many years at least no adequate action can be expected from this source.

Furthermore we must remember that the state is under no obligation to export the products of state-owned forests, and in case of a lumber shortage it would be quite likely to give its own citizens first consideration. At least two states have made recent attempts to prevent the exportation of a natural resource privately owned. The courts declined to sanction such action, but the spirit of these states was clearly disclosed.

REFORESTATION FOR LUMBER PURPOSES A TASK FOR THE FEDERAL GOVERNMENT

Eliminating, then, the availability of private and of state enterprise, the burden of this part of reforestation is thrown upon the

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FIG. 4 FROM TEN TO FIFTEEN YEARS OF AGE SPROUTS ARE OBLITERATING TRACES OF LOGGING; THEY ARE RAPIDLY LOSING THE APPEARANCE OF BUSHES

third agency, i.e., the Federal Government. I have reached this conclusion only after a great deal of thought directed toward finding some other solution of this important problem. Believing firmly in the efficiency of private enterprise I have, in common with many others, been trying to find some way to "sugar coat" this pill so that it would taste good to the individual. We might as well, however, face the facts and stop dabbling with this question. This part of the reforestation problem is inherently one for the Federal Government to undertake. It is distinctly a national question, because its prosecution is for the benefit of all the people.

Forester Greeley, chief of the U. S. Forest Service, in recent testimony before the Senate Reforestation Committee, summed up the whole situation when he said, "In Europe it is usually taken as a recognized policy that the publicly owned forests should be devoted to producing old-growth, high-grade material, because the private forest owner cannot afford to do it, or at least regards it as preferable to produce the lower grades of material that can be harvested much more quickly;" and Secretary Wallace before the same committee said, "Leading forest economists advocate public ownership of at least thirty per cent of the forest lands in order to hasten replacement of timber and stabilize its future production.... To the degree that Federal ownership is extended our future supply of timber will be made more certain and stable."

Admitting, therefore, that we must in the main rely upon the Federal Government, the question arises, How should the Government proceed? The answer to my mind is perfectly clear. The United States should as fast as practicable acquire extensive areas of cut-over lands, unfitted for agriculture in the Lake States, in the Appalachian regions, and in the South. Lands in these sections readily reforest and are comparatively near the great consuming centers. These lands when purchased should become a part of the national forests and subject to the same laws regarding the distribution of the proceeds therefrom. Under the existing statutes twenty-five per cent of these proceeds are paid by the Federal Government to the state for the benefit of the counties within which these lands are withdrawn from taxation.

These lands should be paid for with long-maturity United States bonds, or from the proceeds thereof. This investment will be almost entirely for the benefit of posterity, and if we now select the lands, reforest them, protect them from fire, and pay the interest on the bonds, we shall have done our duty by those who are to come after us. The bonds will ultimately be surely paid from the proceeds of the forests, and a great necessity of the people will be supplied. The plan means an investment pure and simple, and not a raid on the public treasury.

The widest discretion should be given to the Secretary of Agriculture in the selection and purchase of these logged-off lands, but the policy should be clearly indicated that the amount of young

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FIG. 5 LEADERSHIP HAS BEEN PRETTY WELL DECIDED BY TWENTY-FIVE YEARS OF AGE

timber growth will be the most important factor in making the selections and one of the chief measures of value. This will stimulate owners of such cut-over lands to reforest them, give them better protection from fire, and will give reforestation the greatest incentive it has ever had.

In many of the states where the Federal Government owns large tracts of timber there has been more or less complaint from the counties in which these lands are situated because of the large areas thus withdrawn from taxation, and which contribute nothing toward the support of the county administration. To compensate such counties Congress, as I have just stated, passed a law giving them twenty-five per cent of the gross proceeds from the timber sold within their borders. In the case, however, of the Government purchase of cut-over lands, it would naturally be a long time before the counties would derive any revenue from the sale of timber. Therefore, I believe that the Government should annually advance to the states for the benefit of the counties in which these cut-over lands are purchased an amount per acre to be determined as follows: The price per acre at which the lands are purchased shall be multiplied by the average rate of taxation for road, school, and county purposes, in the interested counties, for the three years prior to such purchase, but in my opinion no such advance should exceed five cents per acre per year. This plan would be fair to the counties because they would be assured of a continuous income from lands, many of which would otherwise revert to the state for non-payment of taxes and be taken off the tax rolls. After purchasing, the Government would also relieve the county and state from the cost of fire protection, of road maintenance, and of general administration on the acquired areas.

These advances on the basis described should be a lien against the county's proportion of the proceeds of the forests as and when received. Advances on this basis might be continued until the forests begin to yield a revenue, and thereafter only in such an amount as might be necessary to bring to the county a sum equal to the previous annual payments. The interest on these advances should be remitted as a further remuneration to the county. Repayment of the sums advanced should not be demanded except when the county's revenue from the Government forests exceeds the amount previously annually advanced.

BENEFITS TO BE DERIVED FROM FEDERAL REFORESTATION OF LOGGED-OFF LANDS

From the standpoint of the states themselves, the acquisition of these cut-over lands by the Federal Government, their reforestation

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FIG. 6 MIXED STAND OF WHITE FIR, DOUGLAS FIR, AND REDWOOD—FORTY-FIVE YEARS

and protection from fire, will be of direct financial benefit. In a very few years, states wherein such purchases are made will have vast natural playgrounds and great game preserves which will annually attract hordes of tourists and sportsmen from more populous districts, and from adjoining states which are without forests. Coöperative regulations between the Federal and State Governments, as to the issuing of fishing, camping, and shooting licenses, even at a small charge, will undoubtedly go a long way after a few years toward defraying the cost of fire patrol and protection, and will bring additional revenue to the states.

As the timber is harvested the people of the state will further benefit financially by the additional employment involved, and through the money expended for wages, farm products, and general supplies. We must not lose sight of the fact that much of the land under consideration is producing nothing of value, and is not likely to do so until placed under Federal control and operation. Aside from the direct financial benefits which will accrue to the states, these reforested areas will put great recreation places within the reach of millions of our people. When I say "within the reach," I mean both in point of time and the amount of financial expenditure required to reach and enjoy them. A great educational advantage will also accrue from large Federal purchases, through the many demonstrations of approved forestry practice and better fire protection that will thereby be afforded to the owners of adjacent lands.

That the purchase of these lands would be a profitable investment to the Federal Government is evidenced by the results already attained through purchases under the Weeks law, passed in 1911. This law provided for the purchase and reforestation where necessary of lands to protect the watersheds of navigable streams. Under this 2,142,476 acres had been purchased prior to July 1, 1922. These lands are located in the New England states and in the Appalachian region. They have been purchased from time to time since 1912 at a cost to the Government of $13,725,000, which includes protection and administration to July 1, 1922. An appraisal of these lands was undertaken, and, including $476,000 of cash receipts, the account showed total assets of nearly $19,935,000, or a net gain to the Government of $6,210,000. There is no reason to believe that future purchases will be any less profitable.

There are differences of opinion in the legal profession as to whether or not Congress has the right to levy taxes for the purchase of lands for reforestation purposes. It seems presumptuous for a layman to invade the domain of the law, but because of this lack of agreement I am taking the liberty of giving you my own views, which are, however, supported by the opinion of my counsel.

As you all know, Congress has the power under the Constitution "to lay and collect taxes, etc., to provide for the common defense and general welfare of the United States." Among the many lessons that the World War taught us was the absolute need for large quantities of lumber. We all remember the breathless anxiety for spruce lumber for our own and our allies' airplanes, and we can also recall the rush for lumber for cantonments, etc. We were obliged to send thousands of our expert lumbermen to France to convert its forests into lumber for use at the front in actual warfare. There seems to be no dispute as to the necessity of a supply of lumber and paper in times of peace, and if in view of the prospective timber exhaustion the Federal Government has not the right to provide for a continuous supply of timber products, then the words "common defense and general welfare" in the Constitution seem to me but empty phrases. I believe that Congress not only has the right, but it is its duty to take promptly any necessary action.

As to the amount of cut-over lands that should be acquired by the Federal Government, it is unnecessary and unprofitable to lay down any hard-and-fast program at this time. For the present our course is clearly charted and we should embark at once, and future congresses will have to be governed by future conditions. Whenever and wherever economic conditions permit the profitable

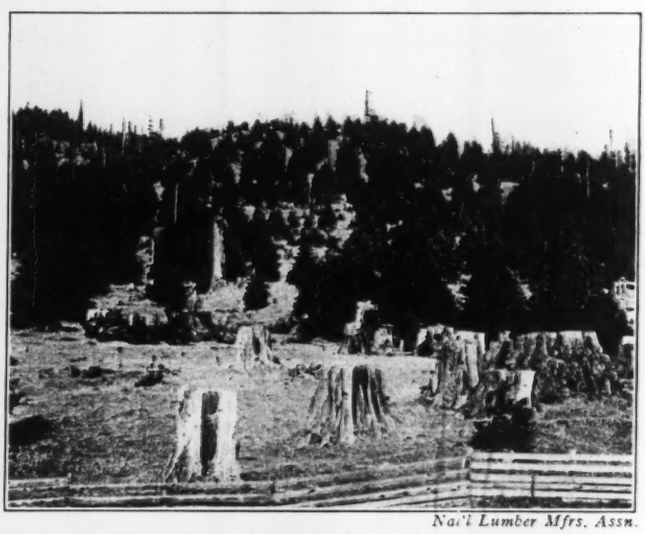

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FIG. 7 TWENTY-FIVE-YEAR-OLD STUMP SPROUTS WHERE FIRES HAVE REPEATEDLY RUN THROUGH

(Compare with Fig. 5 where there have been no large fires since logging.)

engagement of American capital in reforestation, we can depend upon American initiative to take advantage of the opportunity. Until such conditions exist, the Federal Government is the only agency that can step into the breach.

FEDERAL GOVERNMENT WELL EQUIPPED FOR STARTING REFORESTATION ON A LARGE SCALE

Fortunately the United States has complete machinery for starting reforestation on a large scale. The Forest Service of the Department of Agriculture not only has thorough knowledge regarding the location of suitable lands, and the kinds of timber with which to reforest, but it is very intelligently and efficiently directed. It has never had sufficient appropriations, due to a lack of sympathetic comprehension on the part of Congress and of the people

generally as to the great importance of the work entrusted to it.

The purchase by the Federal Government of these logged-off lands for reforestation will not, however, alone settle the problem. Fire protection is an absolute essential. This statement requires no supporting argument, because every one knows that dead trees, be they young or old, will not grow, neither will they reproduce. Furthermore every one realizes that fire does not respect property lines, and therefore fire protection must be general wherever reforestation is in progress. This can only be attained through the coöperation of the Federal and state authorities and the private owners. This coöperative plan is in successful operation in several of the heavily timbered states of the Northwest. The results have been most gratifying during the short time that this plan has been in force, but the Federal Government has not appropriated its proportionate share of the cost.

There is complete justification for Federal contribution toward general fire protection, not alone because of the Government's direct interest through ownership, but because fire protection of timber growth, no matter how young or by whomsoever owned, is of vital importance to all the people. Let me again quote Colonel Greeley, Forester of the United States, who said to the Senate Committee on the question of Federal participation in fire protection:

> I think that the Government should recognize that it has a real obligation in this matter. I do not think we should view the Government's contribution as a subsidy. The states in this country are interdependent upon each other for forest products. A very large proportion of the products of our forests go into interstate commerce, and I think that we should recognize that the Government has a standing obligation to assist in timber growing, in view of the nation-wide interests at stake. While this is largely arbitrary, I would put that obligation at about twenty-five per cent of the cost of protection, assuming in a broad way that it is fair for the Federal Government to pay one-quarter, for the states to pay one-quarter, and for the owners of the land to pay the other one-half.

What Colonel Greeley had in mind, as he explained later, was providing fire protection for cut-over lands of little present value but of the greatest potential value in providing a timber supply for the future.

We have had only logged-off lands under consideration, because in area and future potential value these constitute the larger part of the program. There remain, however, the 138,000,000 acres of mature forests, which should be taken into the picture. As I have stated, these are a part of the 469,000,000 acres that should be kept in continuous timber production. About one-third of the timber in these virgin forests is owned by the Federal Government, and is unfortunately located chiefly in the far-western states, remote from points of greatest consumption. This timber is being capably and intelligently handled, with a view to reforestation as fast as it is logged. All that Congress needs to do for these lands is to make sufficient appropriation to protect them against fire and insects. There is also a considerable area, over one and one-half million acres, of Government forest lands which are not now productive. These should be reforested as rapidly as it can be economically done, and the funds for this purpose might come from direct taxation, but could be properly supplied from the proceeds of long-time bonds.

This brings us, then, to the consideration of the privately owned virgin timber lands. There has been and probably still is a widely prevalent opinion that if the Federal Government could only exercise a supervisory control over the logging of these lands, the question of a future timber supply would be settled. The form which the advocates of this control intend is illustrated by a bill introduced in the last congress. This bill provided in almost so many words, that timber owners who cut their own timber in accordance with the instructions laid down by governmental authorities would only be taxed five cents per thousand feet, but that those who failed to do so should be taxed five dollars per thousand feet. It is needless, of course, to add that this extreme penalty, if inflicted, would mean ruination to the lumber operators, who would be at the mercy of each passing administration. The Supreme Court in its decisions has barred any such invasion of private-property rights, so that this question is eliminated from discussion. However, we must all admit the gross inequity (even if it were legal and practicable) of attempting to impose upon the lumber manufacturer and logger the exclusive burden of providing a future timber supply for this nation. That is a matter which concerns the whole people, and lumbermen should only be asked to pay their proportionate share.

The greatest amount of this privately owned timber lies in the Pacific Coast states, largely in the Douglas fir territory. Of this region, Forester Greeley says:

> In this type the old forest must be removed and a new one started from the seed. There is almost invariably a large amount of seed stored in the heavy duff on the ground. This seed will germinate if given sunlight. Clean cutting, with no attempt to save small trees or advance reproduction (which are usually undesirable species) may be practiced. The essential thing is the prompt burning of slashings before the next growing season after logging. This is necessary both for the general safety of the region and for the protection of the large number of saplings which germinate from the stored-up seed during the first summer after the removal of the timber.

It is clear, therefore, that in this great territory natural reforestation is the rule, and the present logging methods accord with the best forestry practice.

There are some forest sections, however, where reforestation might be better promoted if some seed trees were left. When the Federal Government recognizes new growth as an element of value for purchase, and when state governments give a rational form of taxation, and fire protection is assured, the economic conditions will be so altered that the logger may be warranted in risking a part of his present profits by leaving some trees standing, in the hope of securing a greater profit in the future.

It is contended by some that the ownership of timber land involves a duty to the public to leave seed trees and take all other measures necessary to keep the land in continuous production. If there is any foundation for this contention, it must follow that it is equally a duty of the public to make it economically possible for the individual to do this, or failing in this to compensate him for the timber he has left standing for the public good.

The remainder of the privately owned forests, after deducting those that reforest naturally, is insignificant compared with the utilization of the great areas of lands already cut over and upon which we must rely for a large part of our future timber supply. Generally speaking, in reforestation the matter of continuous management is of greater importance than the practices followed in logging.

I have made no reference to the 150,000,000 acres of farm wood lots because this area, great as it is, need give us but little concern. The farmer is a natural conservator, and for his own uses he must keep his wood lot in a continuous state of forest productivity. He needs shady pasture for his stock in the heat of the summer, and he needs the fuel that the wood lot affords. He naturally markets his mature and more valuable timber, and thus promotes the more rapid growth of the younger trees. The Department of Agriculture is giving him hearty support and coöperation in applying approved forestry methods, and so, as I have said, this great area can practically be omitted from our consideration.

I have attempted to show that the necessary reforestation involves three fundamentals:

1. Large purchases by the Federal Government
2. Removal by the states of the tax barriers to private reforestation
3. Coöperative fire protection by joint contribution from the Federal Government, the state, and the private owner.

This last requires legislative action by the states.

Please keep these three points in mind and render your country a real service by actively participating in their support.

We have been discussing the question of growing a new crop of timber and your duty in that connection as patriotic citizens who have at heart the future welfare of our country.

There is, however, a duty that is just as patriotic and equally important but which devolves almost solely upon the engineering profession. I refer to the prolongation of our existing timber supply through much closer and better utilization of the product therefrom. This requires research sufficient to give a knowledge of the processes and products of the producer and the consumer.

I have not the time, nor is it today my province to go into details, but present conditions are a challenge to every drop of professional fighting blood in your veins.

(Continued on page 72)

Boiler-Test Results with Preheated Air

Data on Elaborate Tests Recently Carried Out on One of the Units of the Colfax Station of the Duquesne Light Company, Showing That Efficiency of Unit is Increased from 5 to 7 Per Cent by Use of Preheater

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THE general arrangement of the preheaters, ducts, dampers and fan is shown in Fig. 1. It will be noted that the installation was made without any addition whatever to the boiler house, the changes required being simply an alteration of the uptake and the cutting of holes through the boiler-room floor for the preheated-air duct. As the drawing indicates, the connection between the common forced-draft duct normally supplying the boilers has been retained and is cut off by means of a shut-off damper when the preheater system is in operation. The air is taken into the preheater from the boiler room directly over the boiler, as indicated in Fig. 1, carried down the duct by the fan and discharged into the

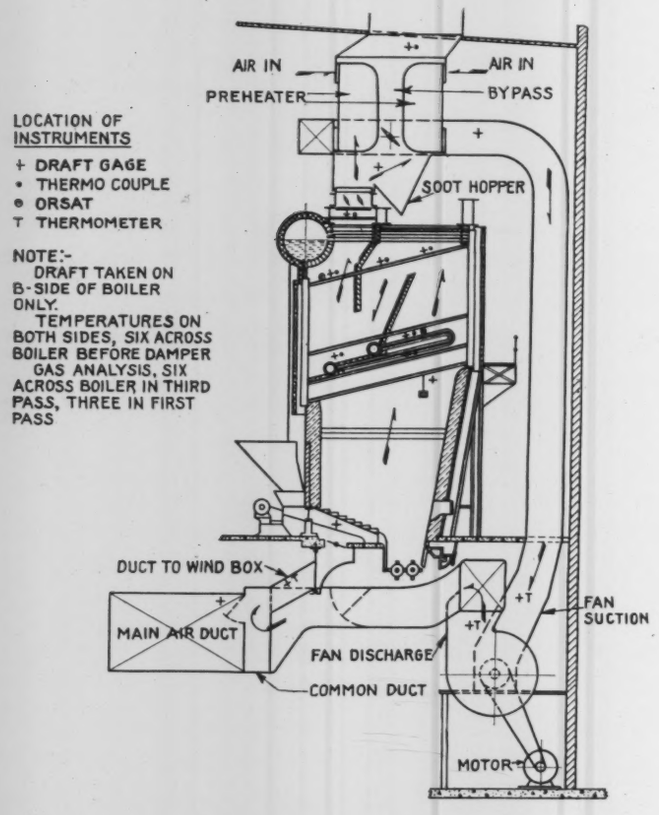

FIG. 1 GENERAL ARRANGEMENT OF BOILER AND PREHEATER SYSTEM AND LOCATION OF INSTRUMENTS

stoker wind box by means of two ducts extending on either side of the boiler. A $7\frac{1}{2}$-ft. double-suction plate fan was used in this installation so that a pressure of 11 in. of water could be carried if found necessary, no exact data on pressure drop through the preheater and duct system being available at the time of installation. Belt drive was used so that various fan speeds could be readily obtained. This fan is now being replaced by a more compact and efficient direct-connected motor-driven unit designed to meet the exact conditions which obtain. The duct work is insulated to prevent loss of heat.

THE PREHEATER USED IN THE TESTS

The preheater itself is shown in Fig. 2 and was constructed by the Combustion Engineering Corporation, following in general the designs of the Underfeed Stoker Company, Ltd., of London, England, excepting in the one important respect that the heating elements are placed back to back and separated by a bypass space fitted with a damper. The preheater is designed for operation when the boiler is evaporating the equivalent of 144,000 lb. of water per hour from and at 212 deg. fahr., which is the normal rate at which the Colfax boilers are operated. It was not considered worth while to install preheating equipment for ratings higher than this as extreme ratings are emergency conditions and the savings obtained would not justify the additional expenditure. When high overload ratings are required the preheater bypass damper is opened to allow more uptake area.

It will be noted that the arrangement of two banks of elements back to back as shown makes available the maximum surface in a given vertical dimension. The preheater was guaranteed to supply air to the wind box at a temperature of 235 deg. fahr., the boiler operating at the evaporation rate given above. These tests indicate that the equivalent of this was actually obtained.

The preheater is riveted and calked, but it was found impossible to make it tight. There is therefore a considerable infiltration of air into the flue gas, resulting in an exaggerated reduction in temperature after the preheater and a reduction in actual preheater performance. A new design using welded construction throughout has been developed and will be used for the installation now under way. An increase in preheater efficiency should be gained thereby.

PARTICULARS REGARDING THE TESTS

The tests which are the subject of this paper were carried on to determine the increase in efficiency of the boiler unit in question when using preheating equipment over and above that obtained without preheating equipment. It will be noted that there are certain local conditions inherent in the arrangement of apparatus for Boiler No. 9 at Colfax which may not obtain for a similar installation in another place. One point the authors have in mind in this connection is that the temperature of the inlet air to the preheater is somewhat high due to the fact that the preheater suction is located directly above the boiler tested. It is their desire to present actual results rather than any calculations which would bring these conditions to a common basis.

The tests presented were run on what is known as Boiler No. 9 at the Colfax Station during the period from July 14 to August 4. As indicated in the test results, the runs were each of twenty-four hours' duration and each series, one series with and one without the preheater, was continuous for the periods of eight and thirteen days, respectively. Better results doubtless could have been secured had a definite effort been made to establish high efficiencies. No such attempt was made. Throughout the test the boiler and stoker equipment were handled by the regular boiler-room force, with some assistance from the Westinghouse-stoker engineers. The operation did not differ from the regular daily method, with the exception of the manipulation of the wind-box dampers to give as nearly a constant rating as possible during the period of each test. In short, every effort was made to have the test results representative of day-to-day operation.

The tests were directed and supervised by Dwight P. Robinson & Co., Inc., assisted by representatives of the Duquesne Light Company, The Babcock & Wilcox Company, and the Westinghouse Company, and were conducted in so far as possible in accordance with the A.S.M.E. test code.

All coal and ash analyses were made by the laboratories of the Duquesne Light Company and checked by separate analyses by The Babcock & Wilcox Company. The readings were taken every fifteen minutes, a signal horn being used to start all observations

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Contributed by the Power Division and presented at the Annual Meeting, New York, December 3 to 6, 1923, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Abstracted. All papers are subject to revision.

at the same time. The boiler and preheater equipment is best described by the following tabulation.

Boiler	Babcock & Wilcox cross-drum water-tube type
Year installed	1922
Water heating surface, sq. ft	22,914
Working steam pressure, lb. per sq. in. gage	275
Normal rating (100 per cent)	79,053 lb. of water from and at 212 deg. fahr.
Tubes	4 in. diam. by 20 ft. long.; 20 tubes high by 51 tubes wide
Drum	60 in. diam. by 34 ft. 1 in. long
Setting	30 ft. 1 in. wide inside of walls
Superheater	Babcock & Wilcox
Location	First pass of boiler
Heating surface, sq. ft	2999
Furnace volume, cu. ft	7500
Stoker, Westinghouse Co. Underfeed, 17-retort, 20-tuyere, extra long with side-wall tuyeres	
Clinker grinder	Double-roll, separate drive on each side of boiler
Projected area of grate (29 ft. 10¼ in. wide by 13 ft. 6 in. effective length), sq. ft.	218.31
Grinder pit section, sq. ft	163.89
Preheating surface, sq. ft	11,200

All apparatus and instruments used in the tests were supplied by the Duquesne Light Company and The Babcock & Wilcox Company's test departments.

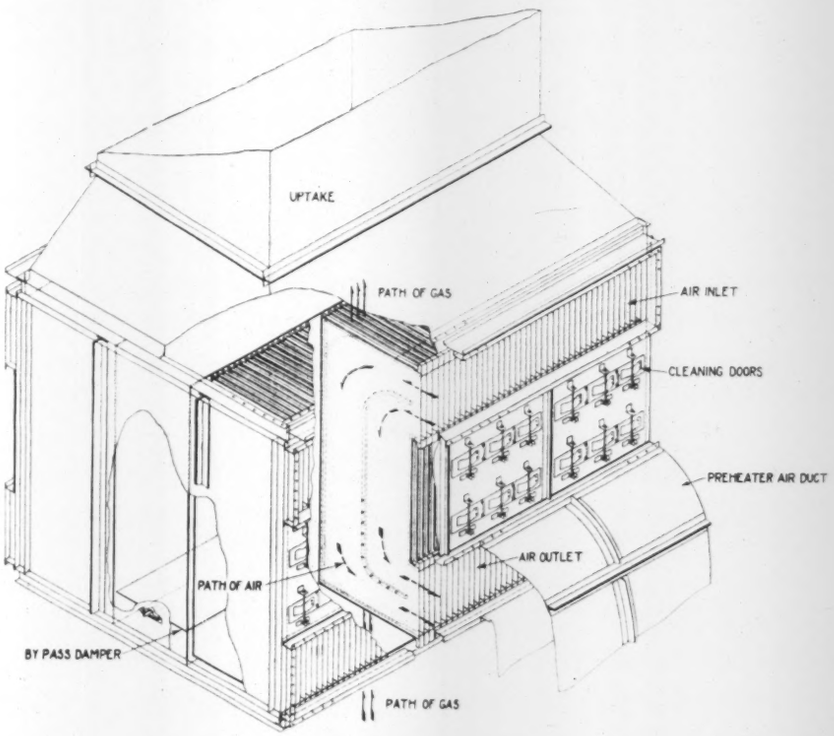


FIG. 2 DETAIL OF PREHEATER

COMMENTS ON TEST DATA AND RESULTS

Referring to the data and results of the evaporative test No. 9 boiler unit with and without air preheater, presented in Tables 1 and 2, the following explanations and comments seem advisable.

It will be noted that the test runs with the preheater begin with test No. 4. Three preliminary tests were run, but due to trouble with the preheater fan these were not considered official.

Gas temperatures above the preheater, shown under Item 14 (*a*) with the preheater in operation, are unduly low because of air infiltration through the preheater.

It will be noted that the flue-gas temperature before the damper, item 14 (*b*), is approximately 15 deg. lower on the average when the air preheater was used. This is due to the higher furnace temperature and better CO_2, resulting in a more efficient heat transfer in the boiler. It will also be observed that Item 14 (*b*) does not check with Item 14 (*m*) due to the fact that Item 14 (*m*) is a reading from the permanent recording-thermometer installation with the element placed in the center of the pass, whereas Item 14 (*b*) is an average of six readings across the path. Readings 14 (*e*) to 14 (*i*), inclusive, are of course subject to the radiation effect of the cold tubes, but they are comparative for the runs with and without the preheaters. The temperature reading below the horizontal circulating tubes, Item 14 (*n*), by recorder is lower than the reading before the damper due to the heat absorption through the tubes.

Draft readings before the preheater, Item 15 (*i*), are somewhat inaccurate on account of the eddy currents set up by the boiler damper which tend to stratify the gases at this point. The draft readings over the preheater, Item 15 (*j*), are very low due to the air infiltration referred to previously.

It will be noted that the pressure readings at the fan discharge, Item 15 (*m*), and the pressure in the duct to the wind box, Item 15 (*c*), do not correspond. This is due to the fact that the duct to the wind box has a considerably larger cross-section than the fan discharge, resulting in a decrease in dynamic head and a higher pressure indication.

The temperature of the preheated air, Item 16 (*f*), was taken at the fan discharge rather than the preheater discharge because the fan decreased the possible error due to stratification. As the preheated-air duct between the preheater and the fan suction is very effectively insulated, the drop in temperature between these two points was considered negligible.

It will be noted that the weight of dry coal per stroke of the stoker rams, Item 19 (*c*), remains fairly constant, thus forming a check on the general accuracy of coal measurement.

The weight of ashpit refuse is calculated from actual weights under Item 22 (*a*) and from coal and ash analyses under Item 22 (*b*). However, the ashpit losses are figured entirely from the laboratory analyses. The weighed quantities are not satisfactory for at least three reasons:

1 It is possible only to estimate the difference in amount of refuse left in the pit above the clinker grinders at the beginning and end of each test. This error is considerable, due to the large size of the clinker-grinder pit.

2 Considerable error is introduced in the ash weights by the presence of moisture, which varies from 20 to 35 per cent, this being determined from a comparatively small sample.

3 No definite determination was made of the amount of refuse carried through the boiler into the stack.

The amount of sprinkler water to the ashpit, Item 24, was measured by meter in the case of tests run with the preheater. It was found that these meters restricted the flow to a large extent and the meters were bypassed when the tests with out the preheater were run. The figures given for the sprinkler water in the case of tests with the preheater are considerably less than those used for general operation.

The figures given under Item 25 (*a*), tank measurements, for the total weight of the water evaporated were used in all efficiency calculations.

The weight of dry flue gas per hour, Item 34, was calculated from the CO_2 readings. These CO_2 readings, although affording a fair indication of the relative conditions for the various tests, cannot be considered as strictly accurate due to the variation in gas composition across the boiler and from front to back in the pass. This variation in gas composition across a section of one of the passes varies as much as 2 per cent in actual value of CO_2, and from front to back of the pass as much as 4 per cent in actual value of CO_2. With an average CO_2 value of 12 per cent these figures correspond to a variation in excess air of 22 per cent and 50 per cent, respectively, so that it is extremely difficult if not impossible to arrive at results actually representative of average conditions across the pass. The analyses of dry gases before the damper as given under Item 51 (*a*) show a complete absence of carbon monoxide, hydrogen, and hydrocarbons. The analysis of gases in the center of the first pass, Item 51 (*b*), shows no indication of carbon monoxide. These tests were made by the Babcock & Wilcox Company chemist and great care was taken in selecting the samples. The fact that no carbon monoxide was found in the first pass of course indicates that combustion is complete shortly after the gas enters the tubes.

Figures shown under Items 43, 52, and 53 are the official analyses reported by the Duquesne Light Company laboratories and checked

TABLE 1 DATA AND RESULTS OF EVAPORATIVE TEST WITHOUT PREHEATER

SERIES 1002-TEST NO.		1	2	3	4	5	6	7	8	9	10	11	12	13	1 to 13 Incl.
8 - Date Started (4:00 P.M.)		7/23/25	7/24/25	7/25/25	7/26/25	7/27/25	7/28/25	7/29/25	7/30/25	7/31/25	8/1/25	8/2/25	8/3/25	8/4/25	7/23 to 8/5, '25
9 - Duration (Hours)		24	24	24	24	24	24	24	24	24	24	24	24	24	312
10 - Kind and Size of Coal		HANNIK MON OF MINE - BITUMINOUS													
AVERAGE PRESSURE AND TEMPERATURE															
11 - Steam Pressure Superheater Outlet, #/Sq."	Ga.	266.3	268.8	268.5	267.9	267.5	267.2	267.2	268.9	265.6	265.7	265.4	263.0	261.2	266.2
(a) Steam Pressure Drum	"	278.0	277.1	277.2	276.2	275.5	274.7	275.5	277.6	275.9	275.8	276.0	278.2	268.8	276.1
(b) Barometric Pressure	"HG.	29.34	29.09	29.26	29.29	29.16	29.04	29.16	29.29	29.32	29.37	29.24	29.21	29.21	29.21
12 - Steam Temperature at Superheater Outlet -	Dy	614.9	612.2	608.0	605.7	605.1	598.5	604.7	611.8	615.3	614.0	618.2	614.1	595.3	608.9
(a) Corresponding Saturation Temperature	"	412.0	412.1	412.1	411.9	411.8	411.7	411.7	412.2	411.2	410.6	410.5	410.3	409.7	411.4
(b) Superheat	"	208.9	200.1	195.9	193.8	191.3	186.6	193.0	199.6	204.1	203.4	207.7	203.8	185.6	197.5
13 - Feed Water Temperature at Boiler -	Dy	120.2	123.4	118.2	121.4	118.2	123.2	122.1	118.8	116.5	118.8	118.5	117.2	126.5	119.8
(a) Heat in Steam above Feed Water Temperature	b.t.u./#	1230.8	1226.2	1229.3	1224.9	1224.9	1219.4	1225.8	1233.6	1234.7	1232.2	1237.3	1233.6	1215.1	1229.2
14 - Average Flue Gas Temperatures -															
(a) After Preheater	Dy	487	415	396	396	372	382	400	437	449	451	422	421	366	406
(b) Before Damper (Thermocouples)	"	535	485	519	506	490	475	486	509	520	519	536	516	466	509
(c) Top 3rd Pass	"	565	561	542	556	518	498	509	536	553	551	540	548	488	534
(d) Bottom " "	"	625	622	596	589	568	536	556	585	609	610	624	601	522	587
(e) Top 2nd "	"	772	758	722	704	661	622	589	694	722	727	753	717	615	702
(f) " 1st "	"	774	752	726	706	668	624	661	696	726	729	766	728	616	704
(g) After Superheater	"	1040	1020	1007	978	949	864	923	963	1021	996	1019	998	870	971
(h) Before "	"	1239	1196	1190	1144	1121	1015	1090	1106	1187	1164	1178	1141	1028	1138
(i) Temperature of Front Wall by Optical Pyrometer	"		2061	2026	1969	1957	1825								
(j) " " Roof " " "	"			2234	2497	2508	2495								
(k) " " Bridge Wall " " "	"			2125	2043	2008	1926								
(l) Average Temperature of Boiler Casing	"	118	143	154	187	187	183	150	159	154	170	163	161	164	154
(m) Temperature before Damper (Foxboro)	"	570	550	543	518	514	492	515	537	553	555	556	546	496	536
(n) " Top 3rd Pass (Bailey)	"	546	535	515	508	488	468	488	506	524	524	536	514	466	507

SERIES 1002 - TEST NO.		1	2	3	4	5	6	7	8	9	10	11	12	13	1 to 13 Incl.
15 - Drafts by Manometer	" Water	Flue .08	.04	.04	.03	.05	.04	.02	.02	.02	.01	.02	.04	.02	.03
(a) Overfire	"	.01	.10	.06	.04	.05	.03	.02	.04	.04	.05	.07	.07	.01	.06
(b) Before Superheater	"	.10	.08	.11	.06	.04	.03	.08	.07	.06	.06	.08	.08	Flue .01	.05
(c) After "	"	.01	.07	.21	.15	.09	.06	.07	.08	.15	.20	.18	.28	.00	.15
(d) Top 1st Pass	"	.21	.26	.22	.17	.12	.07	.08	.15	.30	.49	.51	.53	.01	.17
(e) " End "	"	.56	.65	.52	.44	.32	.23	.29	.42	.49	.61	.92	1.01	.21	.44
(f) Bottom " "	"	.97	1.02	.82	.71	.49	.36	.45	.56	.72	.96	1.22	1.20	.50	.71
(g) Top 2nd "	"	1.11	1.17	.93	.81	.61	.43	.54	.81	.91	1.22	1.18	1.11	.82	.83
(h) Before Damper	"	1.16	1.20	1.05	1.02	1.03	1.24	1.25	1.12	1.24	1.19	1.19	1.25	.95	1.30
(i) " Preheater	"	1.20	1.19	1.21	1.19	1.17	1.15	1.18	1.22	1.21	1.30	1.19	1.15	1.11	1.18
(j) After "	"	1.48	1.44	1.43	1.43	1.33	1.29	1.31	1.39	1.42	1.25	1.40	1.44	1.23	1.38
(k) At Base of Stack	"						.81	.99	1.26	1.29	1.24			1.19	
(l) " Fan Suction	"						7.08	6.96	6.55	6.32	6.34			1.18	
(m) Pressure at Fan Discharge	"	7.57	6.99	6.70	5.81	4.99	4.81	5.15	5.30	5.22	5.27	7.14	6.07	5.19	5.76
(n) " Forced Draft Duct	"	7.48	6.96	6.70	5.78	4.98	4.81	7.21	6.85	6.50	6.47	7.17	6.08	5.80	6.44
(o) " Duct to Wind Box	"	6.83	6.77	6.12	4.78	3.96	3.06	4.06	4.65	4.39	5.40	6.10	5.28	3.66	4.85
(p) " Under Grate	"	3.09	1.54	.13	.00	.01	.00	.01	.18	.18	.70	2.19	.11	.05	.66
(q) " Bridge Wall Air Box	"														
16 - State of Weather -	Dy	Rain	Cloudy	Clear	Clear	Rain	Clear	Clear	Cloudy	Clear	Clear	Rain	Clear	Cloudy	72.4
(a) Temperature of External Air	"	68.4	71.0	68.2	68.4	72.8	75.0	74.2	71.8	73.4	76.3	76.6	74.3	86.0	81.1
(b) " " Air at Main Gauge Board	"	76.3	78.7	76.4	77.6	80.8	80.3	80.7	81.1	81.8	85.2	85.6	83.7	98.2	93.0
(c) " " " " Draft " "	"	88.3	90.6	87.1	88.0	93.0	92.3	98.2	98.8	94.2	97.0	98.6	96.1		
(d) " " " in Main Air Duct	"		105.0	101.0	100.0	109.0			107.0	108.0	110.5	113.0	110.0		98.8
(e) " " " Wind Box	"	97.4	97.8	94.5	95.0	95.5	102.7	94.6	87.0	87.4	91.8	93.0	91.0	100.9	100.2
(f) Relative Humidity	%	67.0	49.0	65.7	69.4	76.0	80.0	60.8	62.8	69.0	66.0	79.0	61.0	68.0	68.0
(g) Dry Bulb Temperature	Dy	79.4	89.8	85.7	89.0	87.0	83.9	94.6	84.3	86.7	84.3	87.6	84.4	90.0	87.9
(h) Temperature of Coal	"	72.8	70.0	71.0	69.0	70.0	71.5	72.2	75.2	75.2	76.7	76.9	75.0	75.5	73.1
TOTAL QUANTITIES															
19 - Total Weight of Coal as Fired -	lbs.	458,975	412,910	354,255	331,800	282,140	231,045	285,555	338,980	391,485	386,260	449,435	359,690	224,040	4,501,570
(a) Average Revolutions of Stoker Sections		1,308	1,159	983	929	791	661	791	938	1,115	1,093	1,235	1,002	628	12,608
(b) Total Ram Strokes	lbs.	22,232	19,705	16,711	15,790	13,447	10,890	13,440	15,864	18,974	18,586	20,996	17,034	10,681	214,347
(c) Weight of Dry Coal Per Stroke		19.87	20.12	20.42	20.45	20.14	20.39	20.38	20.27	19.86	20.11	20.62	20.54	20.07	20.22
20 - Moisture in Coal as Fired -	%	3.74	3.98	3.67	2.68	4.00	3.88	4.07	3.72	3.76	3.24	3.69	3.66	4.31	3.70
21 - Total Weight of Dry Coal -	lbs.	441,809	396,476	341,254	322,908	270,854	222,060	273,935	321,564	376,765	373,745	432,851	346,525	214,384	4,336,140
22(a)Ash and Refuse (Weighed) -	lbs.	83,105	82,810	65,190	59,345	49,065	38,385	46,210	67,170	79,040	89,250	105,540	63,145	42,170	858,465
(1) Total Weight Wet	%	24.19	26.72	22.80	24.84	27.07	22.52	25.66	28.87	25.66	24.93	29.93	29.47	25.73	26.55
(2) Moisture by Analysis	"	14.26	16.51	12.56	13.81	15.22	12.69	15.60	14.84	17.45	17.06	17.08	12.85	15.00	14.55
(3) Ash and Refuse Based on Dry Coal	lbs.	63,002	69,663	62,938	44,607	36,796	26,191	33,059	47,778	58,758	65,215	73,952	44,556	32,163	650,680
(4) Total Weight Dry															
(b)Ash and Refuse (From Analysis) -	%	17.43	19.17	15.94	18.55	15.26	14.25	18.56	18.50	18.77	21.75	19.83	16.50	18.01	
(1) Ash and Refuse Based on Dry Coal	lbs.	77,007	76,004	54,396	59,899	41,332	34,756	38,961	59,649	69,702	70,152	94,145	58,716	38,373	760,112
(2) Total Weight Dry															
23 - Total Combustible Burned (From 22-b) -	lbs.	364,824	320,479	286,872	268,006	229,519	187,316	234,960	261,904	307,056	303,606	338,719	277,795	179,017	3,555,025
24 - Sprinkler Water to Ash Pit -		52	48	44	47	35	34	31	48	48	54	53	38	22	534
(a) Total Revolutions of Clinker Grinder Rolls															

TABLE 1 (Continued)

TABLE 1 (*Continued*)

SERIES 1002 – TEST NO.

		1	2	3	4	5	6	7	8	9	10	11	12	13	1 to 13 Incl.
25 – Total Weight of Water –															
(a) By Tank Measurement	lbs.	3,569,301	3,237,376	2,894,560	2,642,113	2,287,422	1,890,216	2,318,020	2,620,136	3,063,384	2,991,159	3,304,669	2,841,801	1,850,686	35,510,843
(b) " Venturi Meter Integrators	"		3,204,300	2,898,300	2,656,300	2,300,400	1,907,100	2,332,900	2,636,900	3,065,700	2,991,600	3,274,600	2,856,100	1,859,900	
(c) Difference from Tank Measurement	%		Minus 1.02	Plus .16	Plus .54	Plus .57	Plus .89	Plus .64	Plus .64	Plus .06	Plus .01	Minus .91	Minus .30	Plus .49	Plus .07
(d) By Venturi Meter Planimetered Charts	lbs.	3,614,200	3,271,100	2,937,100	2,710,800	2,363,900	1,970,300	2,421,000	2,729,200	3,124,500	3,069,000	3,334,600	3,875,700	1,906,600	36,328,900
(e) Difference from Tank Measurement	%	Plus1.24	Plus 1.04	Plus 1.47	Plus 2.60	Plus 3.34	Plus 4.23	Plus 4.44	Plus 4.16	Plus 2.00	Plus 2.26	Plus .91	Plus 1.19	Plus 3.02	Plus 2.30
(f) By Bailey Meter Integrators	lbs.	3,626,400	3,283,400	2,951,500	2,670,800	2,314,600	1,896,500	2,330,000	2,656,000	3,088,800	3,033,200	3,349,100	2,880,600	1,856,100	36,938,000
(g) Difference from Tank Measurement	%	Plus 1.57	Plus 1.42	Plus 1.97	Plus 1.08	Plus 1.19	Plus .35	Plus .52	Plus 1.37	Plus .83	Plus 1.40	Plus 1.34	Plus 1.37	Plus .40	Plus 1.80
26 – Total Water Evaporated –	lbs.	3,569,301	3,237,376	2,894,560	2,642,113	2,287,422	1,890,216	2,318,020	2,620,136	3,063,384	2,991,159	3,304,669	2,841,801	1,850,686	35,510,843
27 – Factor of Evaporation –		1.2684	1.2686	1.2668	1.2623	1.2643	1.2526	1.2611	1.2712	1.2724	1.2698	1.2750	1.2712	1.2522	1.2667
28 – Total Equivalent Evaporation From and At 212 °F	lbs.	4,527,301	4,090,748	3,666,829	3,335,189	2,891,987	2,375,245	2,923,255	3,330,717	3,897,727	3,798,174	4,213,453	3,612,497	2,317,429	44,980,801
HOURLY QUANTITIES AND RATES															
29 – Dry Coal Per Hour –	lbs.	18,409	16,520	14,219	13,455	11,286	9,253	11,414	13,396	15,699	15,575	18,035	14,439	8,933	15,895
(a) Dry Coal Per Retort Per Hour	"	1062.9	972.0	836.4	791.4	663.9	544.0	671.4	788.1	923.5	916.1	1060.9	849.4	525.5	817.4
30 – Dry Coal Per Sq.Ft of Grate Surface, Per Hour –	"	64.33	75.67	65.13	61.60	51.70	42.38	52.28	61.37	71.91	71.35	82.61	66.14	40.92	68.65
31 – Water Evaporated Per Hour –	"	148,721	134,891	120,607	110,088	94,943	78,759	96,564	109,172	127,641	124,632	137,695	118,408	77,112	113,769
32 – Equivalent Evaporation From and At 212 °F Per Hour –	"	188,638	170,447	152,785	138,964	120,500	98,969	121,802	138,780	162,405	158,257	175,561	150,521	96,560	144,168
33 – " " Per Sq.Ft. of Heating Surface, Per Hour –	"	8.23	7.44	6.67	6.06	5.26	4.32	5.32	6.06	7.10	6.91	7.66	6.57	4.21	6.29
34 – Dry Flue Gases Per Hour –	"	255,492	234,584	217,693	414,338	190,733	160,910	182,738	204,989	216,175	227,210	245,473	216,296	145,519	209,676
CAPACITY															
36 – Percent of Rating –	%	236.7	215.6	193.3	176.8	152.5	125.2	154.1	175.6	205.5	200.2	222.1	190.4	122.2	182.4
ECONOMY															
37 – Water Evaporated Per Lb. Coal as Fired –	lbs.	7.7770	7.8404	8.1708	7.9630	8.1074	8.1812	8.1176	7.8452	7.8250	7.7439	7.3529	7.9007	8.2605	7.8868
38 – " " " " Dry Coal –	"	8.0788	8.1654	8.4821	8.1823	8.4452	8.5114	8.4680	8.1483	8.1508	8.0032	7.6347	8.2009	8.6326	8.1914
39 – Equivalent Evaporation Per Lb. Coal as Fired –	"	9.8639	9.9071	10.3508	10.0516	10.2502	10.2805	10.2371	9.9728	9.9563	9.8332	9.3750	10.0434	10.3438	9.9922
40 – " " " " Dry Coal –	"	10.2472	10.3178	10.7452	10.3284	10.6773	10.6954	10.6714	10.3581	10.3453	10.1625	9.7342	10.4249	10.8097	10.3758
41 – " " " " Combustible –	"	12.4095	12.7645	12.7821	12.6809	12.6002	12.6804	12.4420	12.7178	12.6939	12.5101	12.4394	13.0042	12.9453	12.6527
42 – Dry Flue Gas Per Lb. Dry Coal –	"	13.77	14.20	15.31	15.93	16.90	17.39	16.01	15.30	13.77	14.69	15.50	14.96	16.29	15.09
EFFICIENCY															
43 – B.T.U. Per Lb. Coal as Fired, by Calorimeter –	b.t.u.	12,817	12,762	12,791	12,761	12,935	12,853	12,941	12,733	12,806	12,871	12,844	12,687	12,724	12,807
(a) B.T.U. Per Lb. Dry Coal	"	13,315	13,291	13,278	13,112	13,474	13,361	13,490	13,225	13,306	13,302	13,356	13,169	13,297	13,299
(b) " " " Combustible	"	15,149	15,133	15,157	15,208	15,184	15,178	15,194	15,190	15,147	15,161	15,178	15,116	15,168	15,162
44 – Efficiency of Unit –	%	74.68	75.33	78.53	76.44	76.90	77.74	76.76	76.00	75.45	74.14	70.83	76.82	78.89	75.71
45 – " " Based on Combustible –	"	79.49	81.86	81.94	80.91	80.88	81.07	79.46	81.84	81.32	80.07	79.56	83.48	82.82	80.98

SERIES 1002 – TEST NO.

		1	2	3	4	5	6	7	8	9	10	11	12	13	1 to 13 Incl.
46 – Percent Excess Air –	%	48.58	49.04	53.47	66.04	70.35	75.09	57.31	59.69	39.83	53.50	47.99	59.83	66.39	56.62
51(a)Analysis of Dry Gases Before Damper (By Volume) –															
(1) Carbon Dioxide (CO_2)	%	12.60	11.90	11.59	10.69	10.80	10.15	11.38	11.18	12.43	11.60	11.94	11.18	10.76	11.56
(2) Oxygen (O_2)	"	6.50	7.38	7.67	8.42	8.60	9.05	7.95	8.20	6.66	7.80	7.16	8.02	8.50	7.81
(3) Carbon Monoxide (CO)	"	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(4) Hydrogen and Hydrocarbons	"	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(5) Nitrogen by Difference (N_2)	"	80.90	80.60	80.74	80.89	80.90	80.80	80.74	80.67	80.91	80.90	80.90	80.85	80.75	80.83
(b)Analysis of Dry Gases 1st Pass, (By Volume) –															
(1) Carbon Dioxide (CO_2)	%	13.46	12.80	12.23	11.44	11.80	10.97	11.90	11.56	12.85	12.50	12.57	11.72	10.80	12.00
(2) Oxygen (O_2)	"	5.50	6.80	6.70	7.54	7.48	8.25	7.21	7.54	5.91	6.60	6.45	7.36	8.40	7.03
(3) Carbon Monoxide (CO)	"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(4) Nitrogen by Difference (N_2)	"	81.10	81.00	81.07	81.02	80.92	80.80	80.89	80.88	81.24	80.90	80.98	80.92	80.80	80.97
52 – Proximate Analysis of Dry Coal –															
(a) Moisture (As Fired)	%	3.76	3.98	3.67	3.68	4.00	3.86	4.07	3.72	3.76	3.24	3.69	3.66	4.81	3.79
(b) Volatile Matter	"	33.86	33.62	33.28	30.89	31.94	33.82	33.77	34.81	34.34	33.47	33.82	33.28	34.19	33.44
(c) Fixed Carbon	"	54.00	54.21	54.44	55.31	54.79	54.12	55.01	55.86	55.56	54.27	54.06	53.85	53.48	54.27
(d) Ash	"	12.14	12.17	12.28	13.80	11.27	12.06	11.22	12.95	12.10	12.26	12.10	12.87	12.33	12.29
53 – Ultimate Analysis of Dry Coal –															
(a) Carbon (C)	%	74.07	74.15	74.80	72.75	74.92	74.86	75.26	73.81	73.76	73.85	73.51	73.41	74.08	73.79
(b) Hydrogen (H)	"	5.01	5.10	5.14	5.13	5.15	5.13	5.26	5.04	5.12	5.09	5.16	5.02	5.02	5.10
(c) Oxygen (O_2)	"	6.32	6.10	5.69	5.88	6.12	5.80	5.82	6.00	6.12	6.36	6.62	6.24	6.05	6.12
(d) Nitrogen (N_2)	"	1.19	1.26	1.37	1.28	1.31	1.17	1.29	1.32	1.24	1.32	1.30	1.23	1.24	1.28
(e) Sulphur (S)	"	1.26	1.22	1.22	1.21	1.23	1.28	1.15	1.30	1.14	1.10	1.23	1.23	1.28	1.21
(f) Ash	"	12.14	12.17	12.28	13.80	11.27	12.06	11.22	12.93	12.10	12.24	12.10	12.87	12.33	12.29
54 – Analysis of Ash and Refuse, Etc. –															
(a) Combustible	%	30.33	36.51	22.94	25.61	26.15	22.96	21.16	30.30	34.60	34.67	44.36	35.11	25.26	31.75
(b) Non-combustible	"	69.67	63.49	77.06	74.39	73.85	77.04	78.84	69.70	65.40	65.33	55.64	64.89	74.74	68.25
55 – Heat Balance Based on Dry Coal –															
(a) Heat Absorbed by Boiler (Item 46 x 970.4)	%	74.68	75.33	78.53	76.44	76.90	77.74	76.76	76.00	75.48	74.14	70.83	76.82	78.89	75.71
(b) Loss due to Evaporation of Moisture in Coal	"	.37	.40	.36	.26	.39	.37	.39	.37	.37	.31	.36	.36	.42	.36
(c) " " " Burning of Hydrogen	"	4.30	4.37	4.38	4.42	4.29	4.28	4.36	4.29	4.38	4.32	4.40	4.30	4.17	4.32
(d) " " " Dry Flue Gases	"	10.86	11.16	11.65	12.14	11.87	11.63	11.81	11.71	10.74	11.24	10.50	11.38	10.67	11.23
(e) " " " Carbon Monoxide	"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(f) " " " Combustible in Ash and Refuse	"	5.79	7.69	4.02	5.29	4.32	3.98	5.26	6.29	7.02	7.15	10.56	7.72	4.58	6.28
(g) " " " Heating Moisture in Air	"	.30	.31	.51	.51	.49	.45	.46	.36	.37	.37	.42	.47	.48	.40
(h) " " " Radiation and Unaccounted for –	"	3.70	.74	.75	.94	1.75	1.60	3.86	1.07	1.70	2.47	2.93	Minus 1.00	.85	1.70
TOTAL –		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NOTE – Official Analyses Used.

by independent analyses made in the laboratories of The Babcock & Wilcox Company. The determinations shown are approved by the latter company.

Tests No. 6 to 10, inclusive, as shown in the data and results for boiler No. 9 without preheater, Table 1, were run using the preheater fan for forced draft. The air inlets to the preheater were blocked off and doors in the suction duct to the fan were opened to take air directly from the boiler room. This was done on account of the closer air control possible by the use of the single fan.

Tests Nos. 10, 11, and 12 were intended for high-rating runs, but the ratings planned were not reached due to excessive clinkering. Operation above 220 per cent of rating is not at all reliable under the present conditions.

The reduction of gas temperature through the preheater in the runs without the preheater operating, as indicated under Items 14 (*a*) and (*b*), is due to air leakage and radiation, there being no air drawn through the preheater by the fan during these tests. Readings 15 (*l*) and 15 (*m*) are not complete owing to the fact that tests Nos. 1 to 5 and Nos. 11 to 13, inclusive, were run on the main air duct.

Curves shown in Fig. 3 indicate comparative boiler performance with and without preheated air.

The increase in efficiency due to preheated air as shown by the curves varies from 5½ per cent at 114 per cent rating to 7 per cent at 200 per cent rating, the general effect being a tendency to flatten out the curve in the case of the preheated-air tests. This is due to the increase in heat transmission of the preheater with the increase in temperature and volume of flue gas and air through the preheater, and also to the marked decrease in the percentage of combustible in the ash as indicated in the comparison of curves showing combustible in refuse.

The wind-box temperature increase due to preheater varies from 120 deg. fahr. for 114 per cent rating to 140 deg. fahr. for 200 per cent rating. This higher temperature is the limit that can be reached with the preheater equipment as installed.

The exit gas temperatures are lowered in the case of tests with preheated air, the amount of reduction varying from 15 deg. fahr. at the lowest rating to 10 deg. fahr. at 200 per cent of rating. The reduction is explained by the higher mean gas temperature through the boiler resulting in more effective heat transfer. This increase

TABLE 2 (PART 1) DATA AND RESULTS OF EVAPORATIVE TEST WITH AIR PREHEATER

SERIES 1001 - TEST NO.		4	5	6	7	8	9	10	11	4 to 11 Incl.
8 - Date Started (4:00 P.M.)		7/14/23	7/15/23	7/16/23	7/17/23	7/18/23	7/19/23	7/20/23	7/21/23	7/14 to 7/22, '23
9 - Duration (Hours)		24	24	24	24	24	24	24	24	192
10 - Kind and Size of Coal		HARWICK RUN NO 9 MINE - BITUMINOUS								
AVERAGE PRESSURE AND TEMPERATURES										
11 - Steam Pressure Superheater Outlet, #/Sq."	Ga.	265.1	266.6	268.4	267.5	269.6	266.9	266.6	268.9	267.5
(a) Steam Pressure Drum	"	272.2	275.3	277.6	276.9	278.6	276.0	274.2	276.1	275.9
(b) Barometric Pressure	"HG.	29.19	29.21	29.31	29.45	29.46	29.40	29.32	29.23	29.32
12 - Steam Temperature at Superheater Outlet -	°F	597.2	603.0	616.2	611.4	614.6	616.1	608.3	591.3	607.3
(a) Corresponding Saturation Temperature	"	411.0	411.5	412.1	411.8	412.5	411.6	411.5	412.2	411.8
(b) Superheat	"	186.2	191.5	204.1	199.6	202.1	204.5	196.8	179.1	195.5
13 - Feed Water Temperature at Boiler -	°F	119.1	120.4	116.7	118.4	121.7	116.6	114.9	119.7	118.4
(a) Heat in Steam above Feed Water Temperature	B.T.U./#	1223.2	1224.7	1236.0	1230.9	1229.1	1236.1	1232.9	1219.5	1229.4
14 - Average Flue Gas Temperatures -										
(a) After Preheater	°F	292	275	278	322	339	323	322	273	303
(b) Before Damper	"	459	467	473	499	508	498	489	459	482
(c) Top 3rd Pass	"	482	486	508	526	533	522	512	475	505
(d) Bottom " "	"	529	535	562	579	585	575	564	517	556
(e) Top 2nd "	"	620	659	695	698	710	696	671	594	668
(f) " 1st "	"	626	658	697	702	717	704	679	597	673
(g) After Superheater	"	885	926	986	985	1005	986	941	833	944
(h) Before "	"	1059	1130	1183	1186	1229	1208	1139	1002	1142
(i) Temperature of Front Wall by Optical Pyrometer	"	1883	2054	2019	2099	2134	2067	2053	1952	2036
(j) " " Fuel Bed " " "	"	2701	2619	2633	2715	2739				
(k) " " Bridge Wall " " "	"	2053	2089	2207	2368	2378				
(l) Average Temperature of Boiler Casing	"	133	140	144	157	162	161	168	163	154
(m) Before Damper (Foxboro)	"	500	509	528	535	536	529	518	478	517
(n) " Horiz. Circ. Tubes (Bailey)	"	474	482	495	501	506	502	485	456	486

SERIES 1001 - TEST NO.		4	5	6	7	8	9	10	11	4 to 11 Inc.
15 - Drafts by Manometer -										
(a) Overfire	" Water	.06	.02	.02	.00	.00	.01	.01	.03	.02
(b) Before Superheater	"	.05	.01	.03	.02	.01	.01	.01	.01	.02
(c) After "	"	.03	.01	.02	.02	.02	.01	.01	.00	.02
(d) Top 1st Pass	"	.08	.05	.08	.08	.07	.06	.05	.00	.06
(e) " 2nd "	"	.09	.05	.10	.09	.08	.07	.06	.00	.07
(f) Bottom " "	"	.27	.25	.33	.33	.31	.29	.26	.15	.27
(g) Top 3rd "	"	.39	.40	.51	.52	.50	.46	.41	.19	.42
(h) Before Damper	"	.44	.44	.58	.60	.58	.52	.48	.23	.48
(i) " Preheater	"	.70	1.08	1.10	1.12	1.13	1.12	1.11	1.15	1.06
(j) After "	"	.68	1.05	1.09	1.10	1.11	1.10	1.08	1.09	1.04
(k) At Base of Stack	"	.82	1.11	1.23	1.27	1.29	1.26	1.26	1.21	1.18
(l) " Fan Suction	"	1.74	1.96	2.12	2.20	2.17	2.21	2.09	1.59	2.01
(m) Pressure at Fan Discharge	"	Plus 4.63	Plus 5.21	Plus 4.84	Plus 4.80	Plus 4.82	Plus 4.76	Plus 4.84	Plus 5.54	Plus 4.94
(n) " Forced Draft Duct	"	" 4.03	" 4.60	" 5.04	" 5.05	" 4.69	" 4.81	" 4.79	" 4.25	" 4.66
(o) " Duct to Wind Box	"	" 4.65	" 5.49	" 5.20	" 5.07	" 5.08	" 5.02	" 5.19	" 5.78	" 5.19
(p) " Under Grate	"	" 3.23	" 3.90	" 4.30	" 4.56	" 4.65	" 4.48	" 3.74	" 2.20	" 3.88
(q) Bridge Wall Air Box (Pressure)	"	" .02	" .28	" .62	" .55	" .86	" .17	" .03	" .04	" .32
16 - State of Weather -		Rain	Cloudy	Clear	Clear	Clear	Clear	Clear	Clear	
(a) Temperature of External Air	°F	74	73	74	73	76	78	79	78	76
(b) " " Air at Main Gauge Board	"	80	81	82	82	84	84	89	85	83
(c) " " " " Draft " "	"	88	89	90	90	91	93	96	96	91
(d) " " " in Main Air Duct	"	105	106	104	104	106	106			106
(e) " " Inlet Air to Preheater	"	104	106	104	105	108	111	116	116	108
(f) " " Air at Fan Discharge	"	225	218	229	235	240	238	237	216	229
(g) " " Windbox	"	214	215	225	233	236	234	233	214	226
(h) " " Coal	"	85	85	81	80	75	77	82	80	81
(i) Relative Humidity	%	30.5	34.0	21.5	21.0	21.5	16.0	18.0	18.0	22.6
(j) Dry Bulb Temperature	°F	111.0	106.0	103.0	107.7	113.5	118.5	122.0	120.8	112.8
TOTAL QUANTITIES										
19 - Total Weight of Coal as Fired -	lbs.	244,340	278,385	312,820	328,155	330,965	298,675	266,580	196,410	2,255,330
(a) Average revolutions of Stoker Sections		678	781	868	937	947	850	757	564	6,372
(b) Total Ram Strokes		11,543	13,272	14,761	15,930	16,100	14,488	12,871	9,418	108,383
(c) Weight od Dry Coal per Stroke	lbs.	20.3	20.1	20.6	19.9	19.7	19.8	19.8	20.0	20.0
20 - Moisture in Coal as Fired -	%	3.99	3.94	2.89	3.61	3.96	4.16	4.37	3.65	3.81
21 - Total Weight of Dry Coal -	lbs.	234,591	267,417	303,780	316,309	317,859	286,250	254,930	188,278	2,169,414
22(a)Ash and Refuse (Weighed) -										
(1) Total Weight Wet	lbs.	42,610	47,720	48,605	49,790	48,250	39,685	41,250	33,190	351,080
(2) " " Dry	"	30,803	35,938	38,077	38,712	38,470	31,621	32,625	25,062	271,298
(3) Moisture by Analysis	%	27.71	24.69	21.66	22.25	20.27	20.22	20.91	24.52	22.72
(4) Ash and Refuse Based on Dry Coal	"	13.13	13.44	12.53	12.24	12.10	11.06	12.80	13.31	12.51
22(b)Ash and Refuse (From Analysis)										
(1) Ash and Refuse Based on Dry Coal	%	16.56	14.69	14.73	14.05	13.97	12.96	13.58	15.38	14.40
(2) Total Weight Dry	lbs.	38,848	39,284	44,747	44,441	44,405	37,098	34,543	28,957	312,323
23 - Total Combustible Burned (From 22-b)	lbs.	195,743	228,133	259,033	271,868	273,454	249,152	220,387	159,321	1,857,091
24 - Sprinkler Water to Ash Pit	Gals.		129,186	100,755	81,600	149,635	18 710	133,180	138,100	
(a) Total Revolutions of Clinker Grinder Rolls		28	27	36	39	26	26	26	27	235

in mean gas temperature is due to the decrease in gas quantity as indicated by the increased CO_2 and the higher furnace temperatures using preheated air.

The curves indicate an average increase of CO_2 for the results with preheated air varying from 0.7 per cent at the low rating to 1.4 per cent at 200 per cent rating. This CO_2 increase is due to

The increase in fuel-bed and front-wall temperature for the test with preheated air over that without, shown on curves in Fig. 4, is considerably greater than the increase of the wind-box air temperature on account of the reduction in excess air.

The remaining curves in Fig. 4 are interesting in that they indicate the relative gas temperatures through the boiler.

TABLE 2 (PART 2) DATA AND RESULTS OF EVAPORATIVE TEST WITH AIR PREHEATER

SERIES 1001 - TEST NO.		4	5	6	7	8	9	10	11	4 to 11 Incl.
25 - Total Weight of Water -										
(a) By Tank Measurement	lbs.	2,100,354	2,414,908	2,685,709	2,836,511	2,871,237	2,636,180	2,331,279	1,714,784	19,588,962
(b) " Venturi Meter Integrators	"					2,850,987	2,613,319	2,315,519	1,717,340	
(c) Difference from Tank Measurement	%					Minus .72	Minus .83	Minus .68	Plus .15	
(d) By Venturi Meter Planimetered Charts	lbs.	2,143,000	2,416,100	2,690,100	2,795,900	2,886,800	2,623,300	2,332,800	1,733,400	19,621,400
(e) Difference from Tank Measurement	%	Plus 2.05	Plus .05	Plus .16	Minus1.40	Plus .54	Minus .45	Minus .07	Plus 1.09	Plus .17
(f) By Bailey Integrators	lbs.	2,124,000	2,447,800	2,727,700	2,868,500	2,900,000	2,651,300	2,348,200	1,715,300	19,782,500
(g) Difference from Tank Measurement	%	Plus 1.13	Plus 1.35	Plus 1.56	Plus 1.16	Plus 1.00	Plus .62	Plus .73	Plus .31	Plus .99
26 - Total Water Evaporated -	lbs.	2,100,354	2,414,908	2,685,709	2,836,511	2,871,237	2,636,180	2,331,279	1,714,784	19,588,962
27 - Factor of Evaporation -		1.2605	1.2621	1.2727	1.2684	1.2666	1.2728	1.2705	1.2567	1.2669
28 - Total Equivalent Evaporation From and At 212 °F -	lbs.	2,647,496	3,047,855	3,418,102	3,596,562	3,636,709	3,354,057	2,961,890	2,154,969	24,817,640
HOURLY QUANTITIES AND RATES										
29 - Dry Coal Per Hour -	lbs.	9,775	11,142	12,658	13,180	13,244	11,927	10,622	7,845	11,299
(a) Dry Coal Per Retort Per Hour	"	575	655	745	775	779	702	625	461	665
30 - Dry Coal Per Sq. Ft. of Grate Surface, Per Hour, -	"	44.77	51.04	57.98	60.37	60.67	54.63	48.66	35.94	51.76
31 - Water Evaporated Per Hour, -	"	87,515	100,621	111,905	118,146	119,635	109,799	97,137	71,449	102,026
32 - Equivalent Evaporation From and At 212 °F, Per Hour -	"	110,312	126,994	142,421	149,857	151,530	139,752	123,412	89,790	129,259
33 - " " Per Sq.Ft. Heating Surface " " -	"	4.81	5.54	6.22	6.54	6.61	6.10	5.39	3.92	5.64
34 - Dry Flue Gas Per Hour -	"	153,272	165,459	185,513	193,219	187,270	180,097	170,483	125,897	171,067
CAPACITY										
36 - Percent of Rating -	%	139.6	160.7	180.2	189.6	191.7	176.8	156.1	113.6	163.5
ECONOMY										
37 - Water Evaporated Per Lb. Coal as Fired -	lbs.	8.5940	8.6747	8.5855	8.6408	8.6753	8.8229	8.3700	8.7753	8.6856
38 - " " " " Dry Coal -	"	8.9533	9.0305	8.8410	8.9644	9.0331	9.2059	9.1448	9.1077	9.0296
39 - Equivalent Evaporation Per Lb. Coal as Fired -	"	10.8353	10.9483	10.9267	10.9599	10.9882	11.2298	11.1107	11.0279	11.0040
40 - " " " " Dry Coal -	"	11.2854	11.3974	11.2519	11.3704	11.4413	11.7172	11.6184	11.4457	11.4396
41 - " " " " Combustible -	"	13.3524	13.3860	13.1956	13.2291	13.2992	13.4619	13.4395	13.5260	13.3637
42 - Dry Flue Gas Per Lb. Dry Coal -	"	15.68	14.85	14.64	14.66	14.14	15.10	16.05	16.15	15.14
EFFICIENCY										
43 - B.T.U. Per Lb. Coal as Fired, by Calorimeter -	b.t.u.	12,659	12,884	12,929	13,086	12,879	12,953	12,850	12,851	12,895
(a) B.T.U. Per Lb. Dry Coal,	"	13,188	13,412	13,314	13,576	13,410	13,515	13,437	13,317	13,406
(b) B.T.U. " " Combustible,	"	15,172	15,186	15,191	15,260	15,193	15,207	15,209	15,165	15,201
44 - Efficiency of Unit -	%	83.04	82.46	82.01	81.27	82.79	84.13	83.91	83.40	82.81
45 - Efficiency of Unit Based on Combustible -	"	86.51	85.35	84.29	84.13	84.94	85.90	85.75	86.85	85.31

SERIES 1001 - TEST NO.		4	5	6	7	8	9	10	11	4 to 11 Incl.
46 - Excess Air -	%	59.27	49.21	46.24	45.06	40.89	47.54	57.23	60.77	50.49
51(a)Analysis of Dry Gases Before Damper (By Volume) -										
(1) Carbon Dioxide (CO_2)	%	11.24	12.03	12.27	12.34	12.90	12.40	11.40	11.10	11.96
(2) Oxygen (O_2)	"	8.15	7.32	6.94	6.84	6.10	6.80	7.86	8.20	7.28
(3) Carbon Monoxide (CO)	"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(4) Hydrogen and Hydrocarbons	"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(5) Nitrogen by Difference (N_2)	"	80.61	80.65	80.79	80.82	81.00	80.80	80.74	80.70	80.76
(b)Analysis of Dry Gases 1st Pass (By Volume) -										
(1) Carbon Dioxide (CO_2)	%	11.47	12.18	12.40	12.92	13.03	12.39	11.90	10.88	12.15
(2) Oxygen (O_2)	"	7.70	6.89	6.70	6.10	6.05	6.74	7.28	8.42	6.98
(3) Carbon Monoxide (CO)	"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(4) Nitrogen by Difference (N_2)	"	80.83	80.93	80.90	80.98	80.92	80.87	80.82	80.70	80.87
52 - Proximate Analysis of Dry Coal -										
(a) Moisture (As Fired)	%	3.99	3.94	2.89	3.61	3.96	4.16	4.37	3.65	3.81
(b) Volatile Matter	"	34.31	34.95	33.72	33.73	33.74	32.81	32.06	34.17	33.66
(c) Fixed Carbon	"	52.61	53.37	53.93	55.09	54.64	56.06	56.29	53.54	54.53
(d) Ash	"	13.08	11.68	12.35	11.18	11.62	11.13	11.65	12.19	11.81
53 - Ultimate Analysis of Dry Coal -										
(a) Carbon (C)	%	73.69	73.97	73.67	74.72	74.58	75.10	74.75	74.67	74.53
(b) Hydrogen (H)	"	4.95	5.15	5.09	5.12	4.86	4.61	5.16	5.11	5.00
(c) Oxygen (O)	"	5.81	6.56	6.36	6.59	6.48	5.76	6.08	5.48	6.19
(d) Nitrogen (N)	"	1.34	1.32	1.40	1.30	1.27	1.15	1.24	1.37	1.28
(e) Sulphur (S)	"	1.23	1.32	1.13	1.09	1.19	1.25	1.12	1.18	1.19
(f) Ash	"	13.08	11.68	12.35	11.18	11.62	11.13	11.65	12.19	11.81
54 - Analysis of Ash and Refuse, Etc. -										
(a) Combustible	%	21.02	20.51	16.18	20.45	16.82	14.09	14.01	20.73	17.96
(b) Non-combustible	"	79.98	79.49	83.82	79.55	83.18	85.91	85.99	79.27	82.04
55 - Heat Balance Based on Dry Coal -										
(a) Heat Absorbed by Boiler	%	83.06	82.46	82.01	81.27	82.79	84.13	83.91	83.40	82.81
(b) Loss due to Evaporation of Moisture in Coal	"	.38	.37	.27	.34	.38	.40	.42	.35	.36
(c) " " " Burning of Hydrogen	"	4.11	4.22	4.22	4.21	4.08	3.81	4.26	4.22	4.13
(d) " " " Dry Flue Gases	"	7.00	6.69	6.56	6.90	6.88	7.08	7.34	7.13	6.95
(e) " " " Carbon Monoxide	"	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
(f) " " " Combustible in Ash and Refuse	"	3.65	3.28	2.61	3.09	2.56	1.98	2.06	3.50	2.82
(g) " " " Heating Moisture in Air	"	.23	.22	.12	.14	.17	.15	.19	.17	.18
(h) " " " Radiation and Unaccounted for	"	1.37	2.76	4.21	4.05	3.14	2.45	1.82	1.23	2.75
TOTAL -		100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

NOTE - Official Analyses Used.

better combustion conditions. The fuel bed was much more uniform and there was an almost entire absence of air holes or disturbances of any kind to break up the uniformity of stoker operation.

It will be noted that the percentage of combustible in the ash remains practically constant for all ratings when preheated air is used, the decrease of per cent of combustible over that for operation without preheated air varying from 6 per cent to 12 per cent.

No material change in superheat is indicated.

The curves given in Fig. 5 show a decrease in draft loss through the boiler for preheated-air operation, varying from about 20 per cent reduction for the low rating to 30 per cent for 200 per cent rating.

Fig. 6 indicates the temperature drop through the boiler with and without preheated air for conditions which obtain at 200 per cent of rating. The curves clearly show that the mean temperature for the total travel of gases is higher with preheated air even though the final exit temperature is lower.

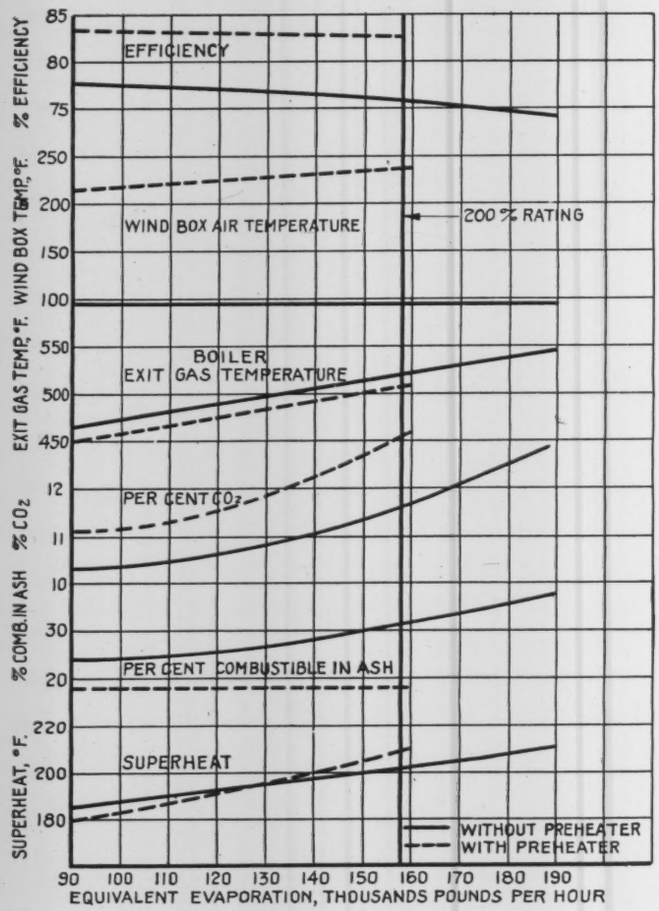


FIG. 3 COMPARATIVE PERFORMANCE OF BOILER NO. 9 WITH AND WITHOUT PREHEATED AIR

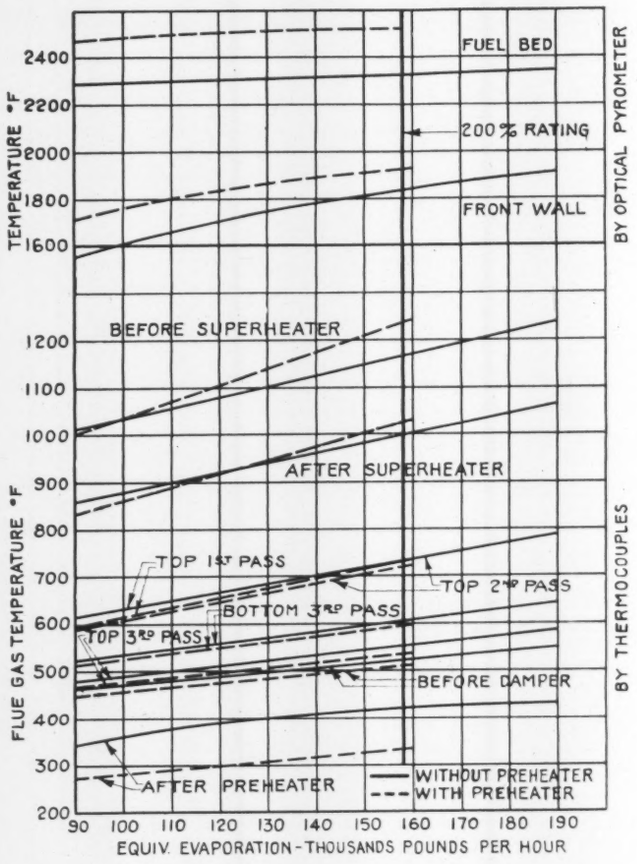


FIG. 4 FURNACE AND GAS TEMPERATURE WITH AND WITHOUT PREHEATED AIR

Figs. 7 and 8 show curves of typical test logs with and without preheated air, respectively. These curves show the variation of the load on the boiler during test with corresponding variations in the other principal readings, and are a representative indication of the continuity of the records.

Charts are given in the complete paper which indicate the frequency of hooking fires for tests with and without preheated air, respectively. These charts show that grinding out of the ashpit was less frequently required in the case of tests using preheated air.

The curves in Fig. 9 show special CO_2 traverses at the top of the third pass and in the uptake before and after the preheater. As noted previously, such traverses were taken once for each test. The curves represent a typical example of the conditions existing. The decrease in CO_2 between traverse in the third pass and traverse in the uptake before the preheater is due to air leakage at the expansion joint between the boiler damper frame and the uptake. The leakage in the preheater causes another drop in CO_2.

Fig. 10 shows the approximate distribution of difference in efficiencies with and without preheated air plotted from cumulative heat-balance curves with the difference in the various losses superimposed on the efficiency curves. These curves show clearly the proportion of the total efficiency gain which is due to better combustion conditions. The heat recovered from the ashpit loss is represented by the difference between curves *EF* and *CD*, but the variation in radiation and unaccounted-for loss brings the net gain to the efficiencies represented by curve *AB*.

ADVANTAGES OF FLUE-GAS AIR PREHEATING

The outstanding advantages of the flue-gas air preheater as evidenced by the installation at Colfax in addition to the gain in boiler efficiencies as presented in the test results are as follows:

1 Simplicity
2 Low cost of installation

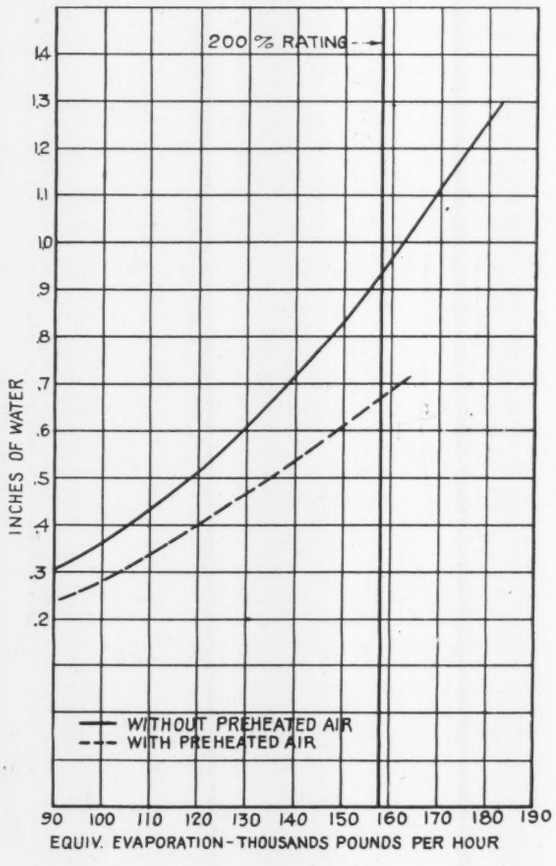


FIG. 5 BOILER DRAFT LOSS

3 Low maintenance
4 Small operating charges.

As has been previously pointed out, the preheater equipment can in many cases at least be installed without any additional building space whatsoever.

The comparatively low cost of the equipment itself is evident from the fact that the total weight of material required to produce the same effect with water economizers is considerably greater and requires the use of an induced-draft fan for the flue gas and a special pumping system for the feedwater.

In the matter of maintenance, it may be argued that the preheater installation at Colfax has not been operated long enough to

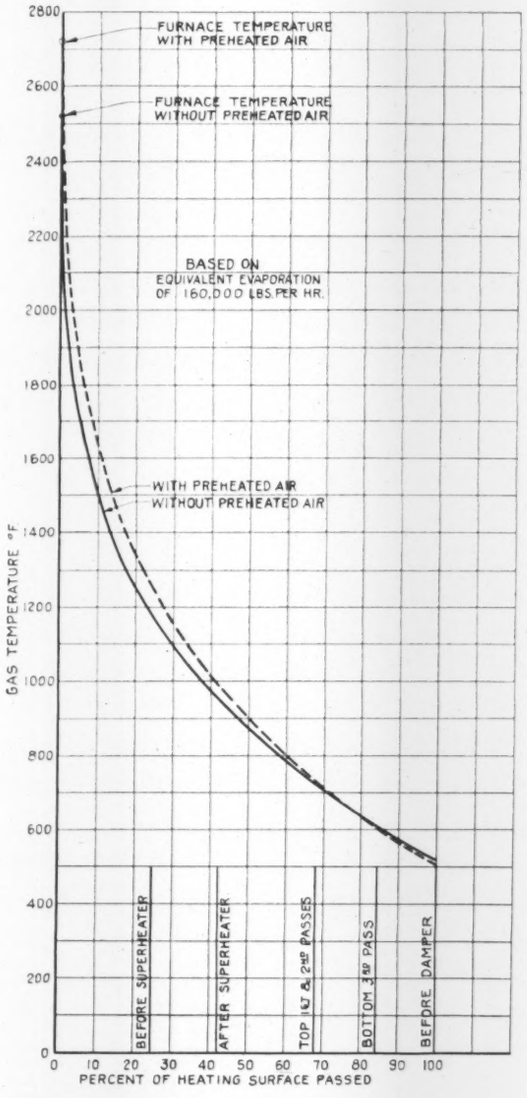


FIG. 6 COMPARATIVE TEMPERATURE DROP THROUGH BOILERS

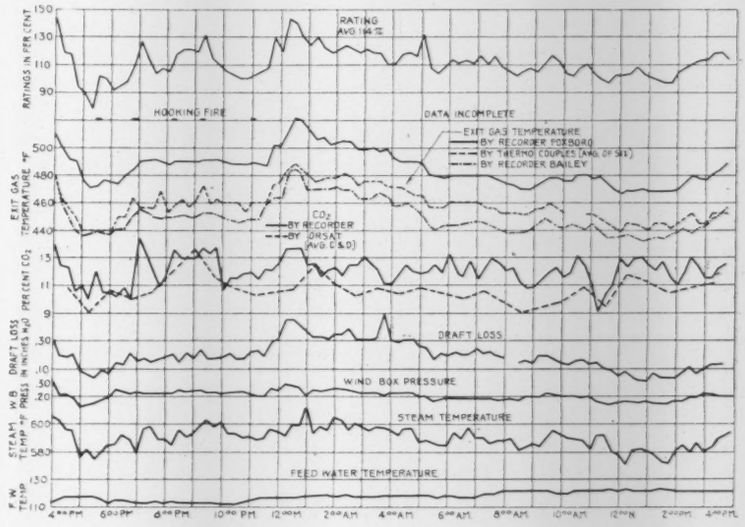


FIG. 7 LOG OF TEST NO. 11 WITH PREHEATED AIR

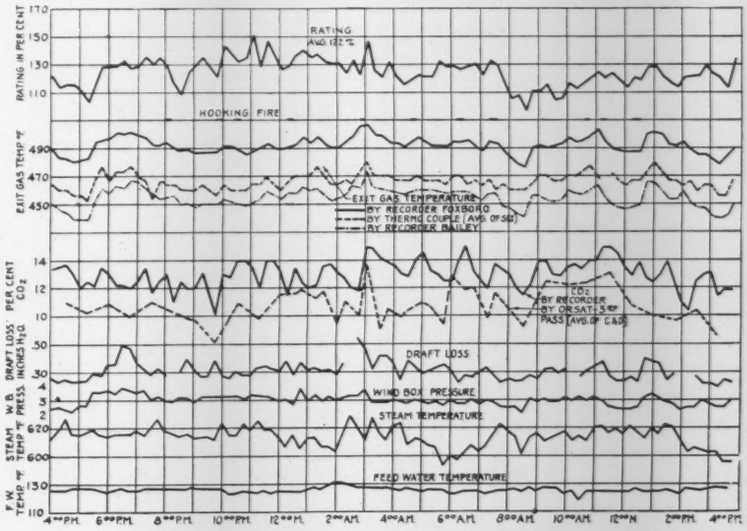


FIG. 8 LOG OF TEST NO. 13 WITHOUT PREHEATED AIR

definitely establish reliable data. However, it is evident that the only item questionable is the preheater-element construction. There has been up to the present time absolutely no indication of deterioration in this connection, and in addition the reduced amount of equipment required for the preheater installation in comparison with an economizer installation naturally reduces maintenance charges.

The only operating cost chargeable to the preheater installation is the power required for moving the air through the preheater and duct system. In this particular installation this amounts to about 5 kw. per ton of coal fired, or the equivalent of less than 0.4 per cent of the coal used in the boiler.

In addition to this, the more even furnace conditions resulting in less troublesome and smoother operation, constitute an asset that is quite real, even though it may be difficult to capitalize its value. In this connection the notes made by the Westinghouse-stoker engineers, covering conditions observed during these tests include the following items:

1 The fuel bed was much more uniform with preheated air and no holes or disturbances of any kind appeared to break up the uniformity of operation
2 The fuel ignited more readily
3 The fuel bed burned much more uniformly throughout its depth
4 There was less combustible ejected from the underfeed section to the clinker-grinder pit
5 Less carbon was contained in the refuse discharged into the ashpit
6 The refuse in the clinker-grinder pit around out with less trouble due to the character of the clinker
7 No clinker trouble of a serious nature was encountered at any time. The clinker itself was harder and more easily handled.

The preheater equipment was placed in operation on May 7 and was in service until June 13, when the boiler was shut down for overhauling prior to the tests. Some readjustments were made in the spacing of elements which had been forced out of line on account of uneven expansion stresses. The boiler and preheater were placed on the line again July 10 and, with the exception of the period for the tests run without preheater, were in continuous op-

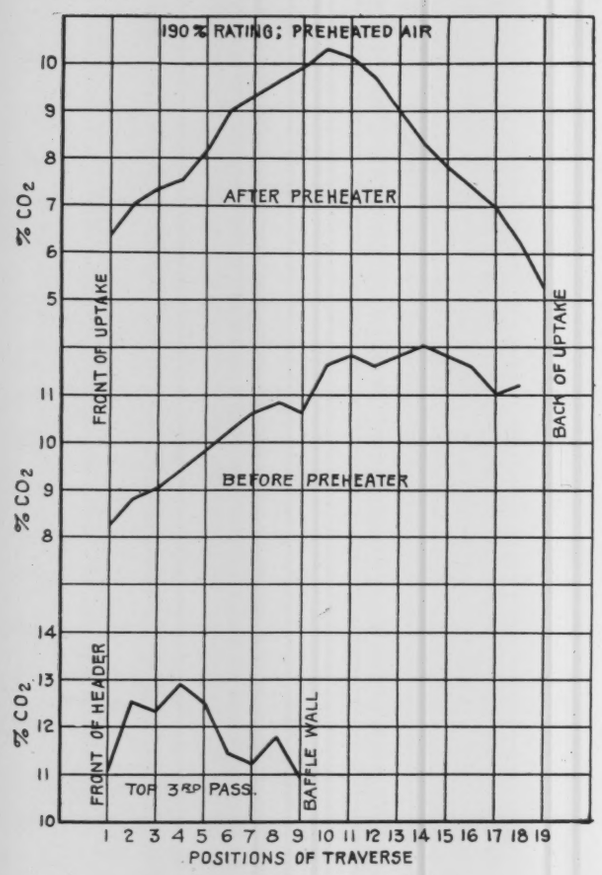


FIG. 9 CO_2 TRAVERSES BEFORE AND AFTER PREHEATER

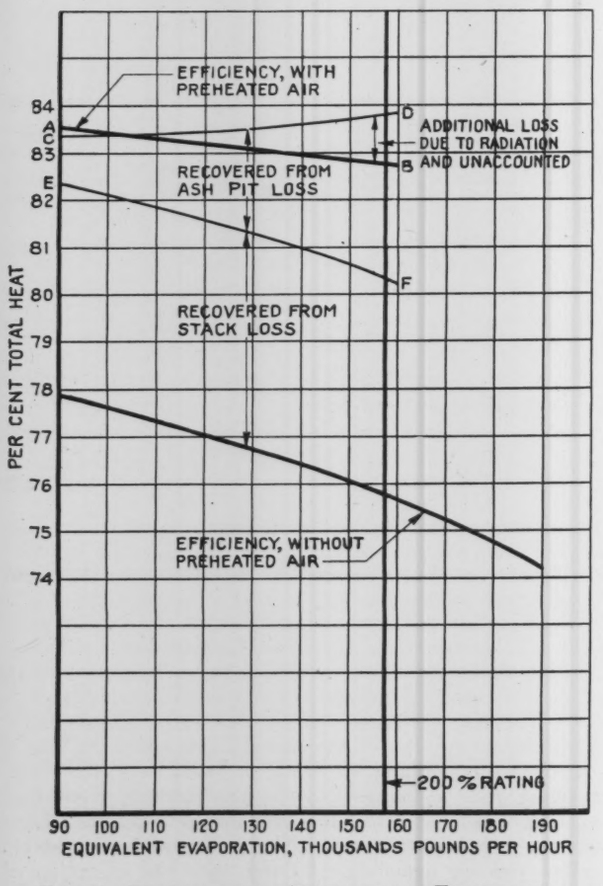

EFFICIENCY, WITH PREHEATED AIR
ADDITIONAL LOSS DUE TO RADIATION AND UNACCOUNTED
RECOVERED FROM ASH PIT LOSS
RECOVERED FROM STACK LOSS
EFFICIENCY, WITHOUT PREHEATED AIR
200% RATING
PER CENT TOTAL HEAT
EQUIVALENT EVAPORATION, THOUSANDS POUNDS PER HOUR

FIG. 10 DISTRIBUTION OF DIFFERENCE IN EFFICIENCIES

eration supplying preheated air until October 19, when trouble with the preheater fan necessitated taking air again from the regular forced-draft-fan duct. Careful inspection of the preheater revealed no indication of soot or other deposits so that it was unnecessary to make use of any soot-blowing equipment, although the installation of such equipment was considered at the time the equipment was put in service. The vertical position of the elements and the weaving of the plates due to temperature and pressure variations, together with the scouring action of the gases, are evidently responsible for this condition.

These tests do not indicate in any sense the limit in temperature which can be successfully used for combustion air. There are no indications whatever of any undesirable effects on the stoker parts or of general combustion conditions which are not favorable to the higher air temperatures used. It is quite probable that still better results could be gained with somewhat higher temperature than that used.

The reduction in boiler-draft loss in a measure offsets the draft loss through the preheater, so that the height of stack to offset the drop in flue-gas temperature is not so great as would ordinarily be expected.

It will be noted that the feedwater temperatures throughout the tests were low. These temperatures do not represent the normal conditions at the Colfax station, but were necessitated by the arrangement of water-measuring apparatus, which did not allow of the water passing through the heater system.

Reforestation and Timber Conservation

(*Continued from page 63*)

A pamphlet recently issued by the United States Forest Service makes this statement:

> Out of a cut of twenty-two and one-half billion cubic feet we waste each year more than nine billion feet. By the elimination of obvious waste in the woods, in the manufacture of lumber, and in its remanufacture and use, by the general application of technical knowledge already available, and by thoroughgoing research in the practice, protection, and utilization of wood, it should be possible to save at least six and one-half billion board feet of lumber each year, and additional amounts of other material. The possible saving in lumber alone is equal to the present yearly growth on 170,000,000 acres.

Therefore, if the engineers of this country can eliminate what the Forest Service terms "the obvious waste," and perfect the methods of protection and utilization of wood, it will be equivalent to planting and keeping in continuous production 170,000,000 acres of forest land. Is the task worthy of your notice? Furthermore, remember that the ultimate consumer has to pay for this waste which has an annual value of over $200,000,000. Think of the burden of cost that would be lifted even by its partial elimination. Conservation is the phase of the timber problem that demands the best efforts of the engineer.

Naturally the query at once arises in your mind as to why sensible men have not long ago dropped these wasteful methods, and why they were ever allowed to come into existence. The detailed answer would add too much to an address that is already too long but we can sum the matter up in a few words. The producer, distributor, and consumer of lumber are following customs which arose years ago when forests were plentiful and lumber was cheap. In other words, both the processes and specifications are apt to be extravagantly faulty, and science as yet has given scant consideration to the problem of utilizing our now unavoidable wastes.

A man not entirely unknown in the engineering profession and who leads in every circle of activity that he touches, has seen the necessity of improving and standardizing the methods of lumber production, distribution, and consumption, and has inaugurated a movement to this end. Under the inspiring leadership of Secretary Hoover, splendidly supported by Secretary Wallace, this work is well started and its successful accomplishment will do much to eliminate waste. Your profession is represented on the committees in charge of this work, but we must have the general coöperation of engineers and architects because the public must be assured that the findings of the committees are on a sound scientific basis.

Economic Phases of Coal Storage

Extent to Which the Practice of Storage Has Already Been Adopted—Inducements to Store Offered By the Periodic Fluctuations in Price and Supply of Coal

By F. G. TRYON[1] AND W. F. McKENNEY,[1] WASHINGTON, D. C.

THROUGH the present discussion of storage of coal runs a certain note of enthusiasm over a new idea, a certain pleasing sense of pioneering in a new field. The studies of the Federated American Engineering Societies, the Fuel Distributor, the Coal Commission, and the Chamber of Commerce of the United States have directed the attention of many engineers to the subject of storage for the first time. The interest thus aroused is most encouraging, but there is danger that in our enthusiasm we shall fail to see the problem in its historical perspective.

In the *Coal Trade Journal* for 1905, for example, there is a series of articles on emergency storage of coal that might almost have been written today. The references to car shortage, strikes, and cost are almost as pat in 1923 as they were when they were published nearly twenty years ago.

Storage, after all, is not an untried thing, an experiment to be urged upon a public entirely unfamiliar with the idea. It is instead, with a great many coal consumers, an established practice of years' standing. The pioneering in coal storage has largely been done, and the task of promoting now lies chiefly in inducing consumers who already store coal to store a little more, or inducing consumers who live from hand to mouth to adopt a practice that others in their own territory have long been following. The economic advantage of storage under some conditions became apparent long ago, and increasing economic pressure is rapidly extending the practice today. The problem of the engineer is therefore not merely to guard against spontaneous combustion, not merely to devise means to cut the cost of handling and reclaiming, but chiefly to show that it pays to store. If the economic incentive can be supplied, storage by consumers will come fast enough.

The aim of this paper is, first, to show how far the practice of storage has already been adopted; and second, to consider the inducement to storage offered by the periodic fluctuations in price and supply of coal.

Extent of Storage as Now Practiced

Storage of Anthracite. Storage of anthracite has now progressed so far that, in spite of the great seasonal fluctuation in demand, the business of mining continues steadily throughout the year. The burden of storage was formerly carried largely by the producers, who constructed immense yards with capacity of a month's output to receive the surplus of spring and summer, but in recent years much of this burden has been passed to the retailer and even to the householder.

Bituminous Stocks on September 1, 1923. To appreciate how far the practice of storing even bituminous coal has progressed, one need only consult the Government's latest report on consumers' stocks on coal. On September 1 commercial consumers and retail coal dealers had on hand an estimated total of 56,000,000 tons of soft coal, which is equivalent to five weeks' output at the present rate of production. This figure does not include 6,400,000 tons on the Upper Lake docks, 440,000 tons stored by the producers at the mines and at intermediate points, the millions of tons in transit in railroad cars and in vessels in river, lake, and coastwise trade, and the large tonnage in the cellars of householders. This 56,000,000 tons is simply what commercial buyers of carload lots had on hand at points of consumption.

Capacity of Present Storage Facilities. Given the incentive, the consumer can find means to store. To equalize the seasonal demand for coal and relieve the winter burden of railway traffic would require the storage during the summer of only 20,000,000 tons more than is already stored. Twenty million tons can be put away without involving the construction of new yards, simply by utilizing more effectively the existing storage facilities or by expanding the crude arrangement of the ordinary small plant.

Days' Supply by Classes of Consumers. At the actual rate that coal was being burned in August the stock on hand September 1, 1923, was sufficient to last 46 days. The relation between different classes of consumers in respect to stocks held is shown by the following table:

	Days
By-product coke plants	30
Steel works	33
Other industrial plants	56
Coal-gas plants	110
Electric plants	52
Coal dealers	38
Railroads	44
Average, all consumers	46

These figures represent averages for the United States. The average is a composite of conditions in localities close to the mines, where small stocks are carried, and of conditions in long-haul localities peculiarly subject to interruptions in supply, where the stocks carried are much larger. Thus, though the average supply at all the industrial plants reporting would last 56 days, the plants in New England carried a reserve sufficient for 141 days. At the other extreme was the State of West Virginia, from which 41 establishments, secure in their connections with the non-union mines of that state, reported an average supply of only 14 days.

Total Tons Held by Classes of Consumers. The largest reserves of coal above ground are held by the general industrial consumers. As shown in Table 1, the general industrials, other than coke ovens and steel works, had 44.1 per cent of the total in consumers' storage on Armistice Day (November 11, 1918), and 32.8 per cent on September 1, 1923. A notable feature is the increase in the relative importance of the stocks carried by the railroads and the electric utilities. Whereas on Armistice Day the railroads carried 20.6 per cent of the total reserve, they now carry 28.0 per cent. The share of the electric utilities has increased from 7.9 to 11.1 per cent. The increase in storage by these two classes undoubtedly represents a deliberate policy to build up fuel reserves. The decrease in the percentage held by the group of "other industrials" is due chiefly to the fact that their stocks on Armistice Day were abnormally large.

TABLE 1 SOFT-COAL RESERVES IN HANDS OF CONSUMERS ON ARMISTICE DAY, NOV. 11, 1918, AND ON SEPT. 1, 1923

(Estimated from reports from 5000 representative consumers to the Geological Survey and the Census Bureau.)

	Per Cent of Total[1]	
	Nov.11,1918	Sept.1,1923
Railroads	20.6	28.0
By-product coke ovens	6.1	7.9
Steel works	5.8	3.9
Other industrials	44.1	32.8
Coal-gas plants	1.8	2.8
Electric utilities	7.9	11.1
Retail dealers	13.7	13.5
	100.0	100.0

[1] Nov. 11, 1918, 63,000,000 tons; Sept. 1, 1923, 56,000,000 tons.

Attention is invited to the large quantity of coal stored in retail dealers' yards. Though retailers as a class do not attempt to carry heavy reserves, their yards commonly hold from 3,000,000 to 9,000,000 tons of bituminous coal and from 2,000,000 to 8,000,000 tons of anthracite.

The stocks of special-quality coals held at coke works and coal-gas plants are more significant than they would seem to be, because these coals can be obtained from only a few districts.

Location of Reserve Stocks. The geographical location of reserve stocks is influenced not merely by the number of consumers in a locality and the amount they consume, but by the fact that stocks increase as distance from the mines increases. The region of greatest density of storage is southern New England. In the three

[1] Division of Mineral Resources, U. S. Geological Survey, Department of the Interior.

A study made for the use of the Storage of Coal Committee of the Federated American Engineering Societies. Contributed by the Fuels Section and presented at the Annual Meeting, New York, December 3 to 6, 1923, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Abridged.

states of Massachusetts, Connecticut, and Rhode Island there were approximately 6,000,000 tons in storage on Armistice Day. Other areas of dense storage are northern New Jersey, New York, Ohio, Pennsylvania, the Detroit district, the Chicago district, and the Upper Lake docks. The fuel reserves of the railroads on the date given amounted to 13,000,000 tons.

Number of Consumers. Storage of large quantities of coal is limited to those who buy coal in carload lots. The Fuel Administration found 90,000 consignees or consignee establishments buying coal in sufficient quantity to be classed as carload-lot buyers. The retailer, of course, supplies practically all the millions of householders with both anthracite and bituminous coal, but he also handles some 30,000,000 tons of bituminous coal for industrial use or for small public utilities, as well as for hotels, apartments, churches, theaters, and the like. The aggregate storage capacity of the bunkers and bins of these small consumers probably runs into millions of tons. Storage of a winter's supply by these consumers may, indeed, be impossible, but it does not follow that larger bunker capacity would not be desirable. If the economic incentive to storage is sufficient, even these small consumers will find means to increase their fuel reserve.

Consumers Who Buy in Carload Lots. Besides the retailers there are perhaps 52,000 consumers who buy in carload lots. They include the public utilities, the railroads, and the larger industrial plants. Among them are companies that practice storage on an enormous scale. But here again the problem is not alone one of building mammoth plants at great factories or at central power stations. The engineer in planning for types and kinds of storage plants must provide also for the typical consumer, and the typical consumer, even among the carload buyers, is a man who uses less than one car a week.

In August, 1918, 65 per cent of the carload-lot buyers in the general industrial class used less than 30 tons a week, and 75 per cent less than 50 tons—equivalent to one car a week. These smaller carload buyers took but 11 per cent of the coal consumed by plants of this class, in sharp contrast to the group of large consumers, who comprised only 4 per cent of the plants but who used 59 per cent of the coal. For the smaller carload-lot buyers, including 75 per cent of the plants, a 90-day reserve would mean a stock pile of 100 to 700 tons. For the 21 per cent of plants that burn 50 to 400 tons a week, a typical 90-day reserve would mean a stock pile of 1200 to 2500 tons. For the group of plants that burn 400 tons or more a week, and consume 59 per cent of the total coal used by the industrials, a three months' reserve would mean a stock pile of 5000 tons or more. There may be a thousand consumers in the country—certainly not more than three times that number—who could maintain a storage plant with a capacity of more than 5000 tons. The stocks of small consumers usually range somewhat higher in days' supply than those of the larger users.

Unequal Stocks of Provident and Improvident Consumers. It would be a mistake to suppose that stocks are evenly divided—that all consumers, even in a given class or a given locality, are protected by equal reserves. In every community some consumers habitually live from hand to mouth, and others habitually carry a reserve even larger than that which may be warranted by the condition of the market.

It is therefore important to note how the stocks of a given class of consumers vary in different plants. The heaviest stocks were carried in the early part of 1919, at the end of the war, after an intensive campaign by the Fuel Administration to induce all buyers of coal to store in anticipation of another winter of hostilities. The mines had produced and the railroads had transported more coal than ever before. Some 40,000,000 tons had been placed in consumers' storage during the year, and the condition more nearly represented general saturation than ever before, yet even then, 60 plants out of the 2350 reporting to the Geological Survey and Census Bureau were carrying less than two days' reserve and 122 were carrying two days' but less than seven days' reserve. At the other extreme there were 220 plants—nearly 10 per cent of those on the selected list—with a reserve in excess of 210 days. Though the average plant has a stock of 88 days, and though the weighted average stock of large and small plants was sufficient for 65 days, yet fully one-fourth of the plants had coal for less than 28 days.

Range in Stocks of June, 1920. Still more significant was the condition on June 1, 1920, when the "coal panic" of that year was approaching its height. Seven per cent of the industrial plants reporting on that date, had been reduced to less than two days' supply, and these were not plants supplied through retail channels but plants whose fuel came directly to their own sidings. Twenty per cent of the plants had less than 7 days' supply, and 36 per cent less than 14 days' supply. Under such conditions the fact that some other plants had a reserve for 200 days availed little to tranquilize the market. The resistance of consumers to an increase in price was predicted not upon the average stocks, which were sufficient for 24 days, but rather upon the distress of plants that were either out of coal or momentarily expecting to be, forced to accept any terms offered by the speculators, and frantically competing against other consumers in the same predicament.

The condition of the electric utilities, compelled to continue operating and limited by their own rates in the price they could afford to pay, was even more serious. Though the weighted average stocks of 342 plants reporting on that date were sufficient to last 22 days, 9 per cent of the plants had coal for only one or two days, 22 per cent for less than 7 days, and 47 per cent of them would have been entirely out of coal in two weeks. Small wonder that the consumers, seeing the price rise by leaps and bounds, and failing to receive deliveries on their contracts, felt constrained to buy regardless of price.

THE INCENTIVE TO STORE

The Coal Commission and the F.A.E.S. studied the cost of storage. Adequate records of its cost are difficult to obtain, but it appears that, counting interest on capital tied up in coal and equipment, and overhead expense and degradation of coal, the cost is seldom less than 50 cents a ton and often as much as a dollar or more a ton.

Obviously no one, whether producer or consumer, will incur this expense unless he expects to be compensated for it. Regardless of what may appear socially desirable, individual business men are not going to store coal in order to make more work for coal miners, or in order to relieve the railroads, or in order to tranquilize the market. The business man will store if and when he thinks storage will pay him individually. The fact that storage has become so widespread indicates that many business men have already decided that storage is advantageous.

Storage at the Mines. One simple and obvious way to make mine storage attractive to the producer would be to give a stock pile a rating in the distribution of cars. If by accumulating a stock an operator can get a greater share of the available cars at time of car shortage and attractive prices, he will have an incentive to store of the most positive kind. The public, however, can gain no advantage from storage at the mines, and attention is called to it only because it has met favor in other places.

Storage of Intermediate Points. With the conspicuous exception of the docks at the head of Lake Michigan and Lake Superior and of certain tidewater docks in New England, storage at some point between the mines and the points of consumption is seldom attempted and does not promise to become very important in the country's above-ground reserve of fuel.

STORAGE BY THE CONSUMER

Expanding Present Facilities. The ordinary buyer of coal in carload lots, if he really bestirs himself, can store a much larger quantity than he commonly carries, as was proved by the accumulation of stocks during the war. Because of the great number of such consumers their storage practice has in the aggregate a pronounced effect on the market; and if they can withdraw therefrom in time of active demand it will help to stabilize prices.

Changes in Price. What is there to offset the cost of storage? Leaving out of consideration its effect in stabilizing prices, the advantages claimed for storage are (1) saving in price through purchasing when coal is cheap, and (2) insurance against shutdown of plant. Barring special coals and extraordinary occasions, the question of the economic advantage of storage resolves itself into ascertaining the differential in price between periods of abundant supply and periods of shortage.

Spot Prices as an Index to Economic Incentive. The "spot"

price or "open market" price refers to coal for prompt delivery, or even coal already shipped, which is available for purchase by car number. It is commonly higher than the contract price at times of active market and somewhat lower than the contract price at times of dull demand. Short-term contracts for a period of delivery that includes only a month or two are not greatly different from spot sales and normally are made at about the spot price.

The typical consumer who uses more in winter than in summer can cover his steady, all-the-year-round requirements by contract, but to get the extra tonnage that he needs in winter he must either store his coal or buy it in the high spot market of winter. His choice between these alternatives, if he makes it intelligently, turns on whether or not the difference between winter and summer prices is sufficient to offset the cost of storage.

As the consumer has always the option of buying in open market, he is not justified in buying on contract except when he feels that in the long run he can do just as well as in the open market; and the test of the value of storage to him turns on whether or not its cost is kept within the range of the spot price.

Failure of Contract Deliveries. Final proof that the fluctuations in spot price must be carefully weighed by any one who is considering storage is found in the all-too-frequent failure of contract deliveries at times of shortage. A contract with a union operator ceases to produce coal when the miners strike, and even a contract with a non-union operator may be temporarily converted into a scrap of paper by a railroad embargo or an I.C.C. priority order. It is safe to say that there is hardly a consumer who has not been forced to purchase in the open market during one or more of the crises in coal supply of the last two years. The fluctuations in spot price therefore lie at the very bottom of the problem whether it pays to store.

An examination of the curve of spot prices for the last twenty years reveals three kinds of fluctuations: long-time changes associated with business conditions, seasonal fluctuations, and fluctuations associated with strikes of coal miners or breakdown of railroad transportation.

Fluctuations in Spot Price Associated with Changes in General Business. The business depressions of 1908–09, 1914–15, and 1921, and the great upward sweep of commodity prices from 1916 to 1920, left their mark in the general movement of spot prices as well as in the average sales realization. Storage in anticipation of these broad underlying changes is not feasible because they are so far apart, because the recovery from depression is so gradual, and because it is difficult to forecast exactly the occurrence of the trough of depression or the peak of prosperity.

Seasonal Differentials in Price. The record of the "odd" years before the war, when the seasonal factor was free to express itself without interference from other disturbing causes, discloses a regular seasonal swing in the price of certain types of coal in certain localities. For prepared sizes the normal expected differential in the Middle West was sufficient to pay a large part of the cost of storage, but as many consumers did not know how to store this coal they could not take full advantage of it. The differential in the price of smokeless coal prepared for domestic use was so great that it practically carried the cost of storage. The differential in prices of mine-run western coal was not sufficient to bear the entire cost, but it would have carried a considerable part of it. For the coals of the Appalachians, the differential offered by seasonal changes in price was relatively small and quite insufficient of itself to bear the cost of storage. Further east, on the Atlantic seaboard, the seasonal prices offered practically no inducement at all.

Much larger differentials marked the prices before and during general suspensions of mining at the termination of wage agreements in the "even" years. These differentials, and still more the actual stoppage of supply, did induce storage in anticipation of the strikes.

The evidence warrants the conclusion that in the region west of the Appalachians a consumer who counts the cost of storage may expect to derive a benefit from the seasonal variation in price, year in and year out, sufficient to meet a considerable part of the expense of storage. If at the same time he anticipates other increases in price due to strikes, car shortage, or similar conditions, all the factors together conclusively favor storage.

In the East the case for storage must rest upon other causes than seasonal price.

Fluctuations in Price Attending Shortage in Supply. So violent have been the changes accompanying the turbulent conditions of the market since 1916 that they have quite obliterated the seasonal effect.

The curve of spot prices from 1914 to the present time, Fig. 1, shows three periods of distress and high price. The first, which began in the fall of 1916, really lasted until early in 1918, for though the price was nominally fixed by the Fuel Administration in August, 1917, the distress of consumers continued for months thereafter. The second period really began with the strike of November, 1919, and ran through 1920. The extreme high point of $9.51 was reached in August of that year. The third period began in June, 1922, and lasted until March, 1923.

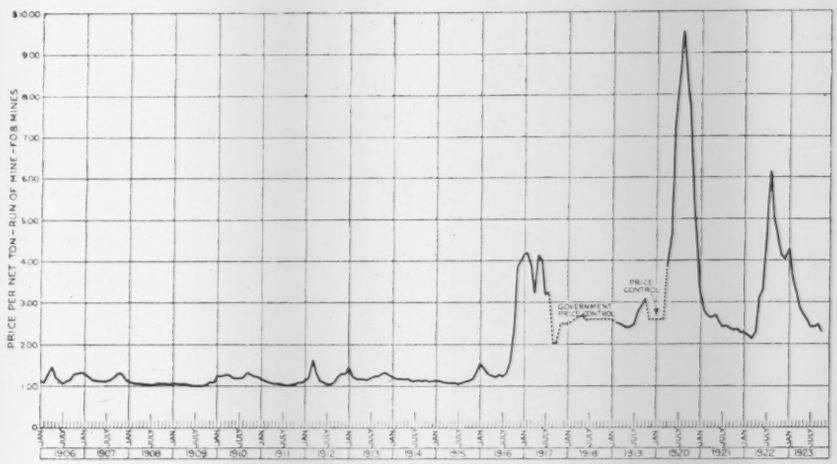


FIG. 1 MONTHLY AVERAGE SPOT PRICE OF BITUMINOUS COAL F.O.B. MINES

(Data for 1913–1923 are C. E. Lesher's average spot prices on 14 coals, representative of nearly 90 per cent of the bituminous output of the United States, weighted with respect to proportions of slack, prepared, and run-of-mine normally shipped and with respect to the tonnage of each normally produced. Data for 1906–1912 have been compiled in as nearly the same way as the records permit.)

Clearly, if the buyers had been able to foresee these tremendous peaks and valleys in the price, storage would have paid, and paid richly. The price in December, 1916, was $4.01, as against $1.22 in July, an increase of $2.79 a ton. Those who had built up large reserves in anticipation of a labor disturbance in April, 1916, were richly rewarded for their foresight. Surely under such conditions it would have paid to store.

For the summer of 1917 and the following winter the spot price does not tell the story. At no time during the summer did the price decline so far as to make storage seem attractive, yet buyers continued to purchase coal anticipating further increase in price. And though the price was fixed at lower levels by the President's proclamation, the heatless days and lightless nights of the winter following were a more serious consequence than a simple rise in price. Here again those consumers and those communities which were well protected with reserve stocks realized that it had paid to store.

Throughout the last nine months of 1918 the Fuel Administration urged upon all shippers large and small the accumulation of the maximum possible stock, and when the Federal prices were lifted in February, 1919, the market sagged. Consumers failing to profit by the lesson of the war burned up their stocks and stayed out of the market. As a result, the strike of November, 1919, caught them unprepared, and caused great inconvenience and even suffering. The price was held down for five months by the restoration of the wartime maximum. Immediately thereafter it shot up to the highest levels hitherto recorded. Most of the consumers made the mistake of drawing heavily upon their stocks during the summer of 1919. Those who were wise enough to follow

the opposite course were protected by large reserves when the strike broke and came through the season of 1920 in relatively easy fashion in spite of the transportation jam, the frantic demands of the export trade, and the panicky condition of the interior markets. It is perfectly clear that the consumer who bought coal for storage at $2.50 in the summer of 1919, and who held it long enough to stay out of the market during even a part of 1920, made large savings.

Again, in the fall of 1921 and the winter of 1921–22, the shadow of a great labor disturbance was cast before. Consumers at that time had to choose between storage and no storage. Those who were deceived by the steadily declining market into laying in no reserve had to buy coal during the strike at prices as high as $6. Here again it paid to store.

In these recurring periods of plenty and scarcity, the difference in spot price does not tell the full financial loss to the improvident consumer. Many a plant had to take substitute coal unsuited to its needs and obtained from it so much lower efficiency that the actual cost per heat unit developed increased in higher ratio than the simple increase in price. Besides, many of the emergency supplies of coal, obtained perhaps under priority order, come from districts remote from the point of consumption and are therefore subject to high freight charges, so that the differential in actual cost to the consumer becomes still higher.

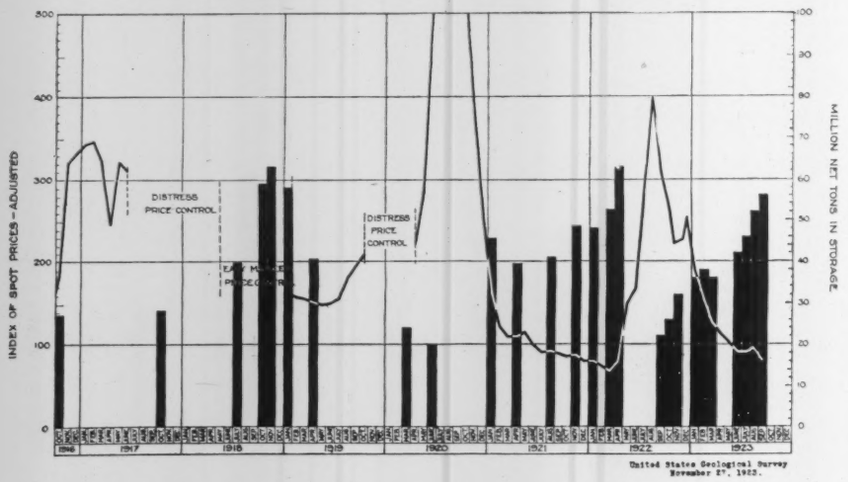


FIG. 2 RELATION OF CONSUMERS' STOCKS AND SPOT PRICE OF BITUMINOUS COAL

(Black columns represent tons in hands of commercial consumers and retailers on all dates for which a canvass of stocks was made. Curve represents *Coal Age* index of spot prices, f.o.b. mines, the average price July, 1913, to June, 1914, being taken as 100; from which has been subtracted, however, the amount of increase in the index of union wage rates during the same period. This adjustment permits rough comparison of the fluctuations in price and the changing conditions of the market, eliminating the factor of wage increases. The possible error in this approximate adjustment is so large that the figures do not show whether the operators are making larger or smaller profits than in 1913.)

Under these circumstances there can be no question that it has paid to store if the buyer bought when the price was low and could stay out of the open market when it was high. Not all the peaks in price, however, could be foreseen. The great strike of 1922 was apparent months before to any but the most casual observer of the market. On the other hand, the strike of 1919 came unexpectedly and gave not more than six weeks' warning at the most. The conditions of the winter of 1917–18 were foreseen, but it was not easy at any time to obtain coal for storage.

Consumers' Stocks Control the Price. The point to be emphasized in the study of this period however, is the powerful influence which stocks themselves have upon the price. Fig. 2 illustrates the direct relation between spot price and the total tonnage of coal in storage. In this diagram the black columns represent the total quantity in the hands of commercial consumers on all dates of record from October, 1916, to September, 1923. The condition of stocks in between the black columns is not known exactly, but may be inferred from the other facts of supply and consumption. Across the diagram moves a jagged line of spot price. The price is based upon the data shown in Fig. 1, except that here it is corrected by subtracting the increase due to the successive changes of the union wage scale. The purpose of making this correction is to eliminate a factor not directly connected with the market and to bring out more clearly the striking relation between the reserve in consumers' storage and the spot price.[1]

By thus superimposing the figures showing stocks upon the curve showing price, the peaks and valleys in the price curve are largely explained. Production alone does not control price. Production was establishing new records throughout the shortage of 1916 and 1917 and in the end nearly every consumer got his coal. A drop in production does not seriously affect prices until it is registered in lower stocks. As shown in the diagram, every time stocks have fallen below 30,000,000 tons the price has immediately increased, and when it has dropped close to 20,000,000 tons the market has been in a state of panic and there has been every evidence of distress. Thus the high prices that were current late in 1916 are directly associated with low stocks, and just as there was no opportunity to rebuild stocks between that time and the corresponding period in 1917, so there was no relief in the spot price. So direct is the relation in the rest of the curve that we might almost plot the course of what prices would have been during the life of the Fuel Administration had they not been fixed by Government order. Low stocks in the fall of 1917 meant distress of consumers and would have meant runaway prices if the price had been free to respond. On the contrary, when stocks had been built up to a high level late in 1918, there were districts in which the operators could not have obtained even the maximum price set by the Fuel Administration. Again, the panic price of 1920 was related to extraordinarily low stocks, the consequence of the miners' strike of the preceding autumn, of severe weather in February, and of the switchmen's strike, which handicapped the railroads from April to June, 1920. When, by the end of 1920, stocks had been adequately built up, the price quickly dropped to normal. Large reserves were maintained throughout 1921 and the price was correspondingly low. So dull was the market at this period that non-union operators cut wages, and coal from union mines was sold at the barest margin if not at a positive loss.

Again, it was not until the heavy reserves built up in anticipation of the 1922 strike had been reduced below the level of safety that the price rose wildly. The same almost perfect inverse correlation is shown by the course of stocks and the course of prices since the settlement of the strike in September, 1922. As stocks have risen prices have fallen, and the spot price did not fall back to normal until stocks had reached what seems to be the normal quantity of 40,000,000 tons, in June, 1923.

The lesson is obvious. Consumers collectively have the power to make or break a market. The relation between the consumers' reserve and the price is almost mathematical. A reserve below 30,000,000 tons indicates a seller's market; 20,000,000 tons indicate a panicky market; and above 40,000,000 tons indicates a buyer's market in which salesmen again take the road and begin to solicit business on the consumer's terms.

How Much Should Individual Consumers Store? The record also includes a lesson for the individual consumer. If he is to profit to the full from the policy of storage, let him store more than

(*Continued on page 108*)

[1] Since reading this paper I have been asked whether the fact that the index of spot prices thus adjusted is now lower than it was in 1913, means that operators are now making smaller profits than they did in 1913. I answer that the adjusted index contains such a large margin of error that it cannot be used to show comparative profits. The adjustment consists of subtracting from the *Coal Age* index of spot prices the amount of increase in the Bureau of Labor Statistics index of union wage rates. To use the corrected index as a measure of profits would involve assuming (1) that labor costs have increased in exactly the same proportion as the wage rate; (2) that other costs have increased in exactly the same proportion as labor costs; (3) that non-union wage rates have increased in exactly the same proportion as union rates, and (4) that all coal is sold at the spot price. None of these assumptions is true. It is clear that at the moment profits of bituminous operators are small, but whether they are smaller or larger than in 1913 cannot be proved by this diagram. The margin of error is not so great, however, as to invalidate the conclusion that high prices are correlated with low stocks, and vice versa.—F. G. TRYON.

A Graphical Study of Journal Lubrication

By H. A. S. HOWARTH,[1] PHILADELPHIA, PA.

This paper visualizes the characteristics of the oil film and the pressures within it for a journal completely surrounded by its bearing. The influences of clearance and viscosity upon the journal friction are quantitatively shown by means of a chart that can readily be used for designing bearings. Several interesting examples are solved by means of this chart. A few of the characteristics of the journal partially surrounded by the bearing are also shown by curves.

THE hydrodynamic theory of lubrication, first developed by Osborne Reynolds and subsequently simplified by A. Sommerfeld and W. J. Harrison, forms the basis of this exposition. An attempt is made to express the theory in a way that will be easily applicable to the solution of practical problems. Much of the early mathematical treatment of the subject looks formidable, and therefore does not encourage general study. Fortunately, W. J. Harrison, Fellow of Clare College, Cambridge, England, has presented the subject in simple mathematical form in his paper The Hydrodynamical Theory of Lubrication..., which appeared in the Transactions[2] of the Philosophical Society, Cambridge, in 1913. His formulas are given below and are used for plotting the curves that follow.

The case of a journal completely surrounded by its bearing will

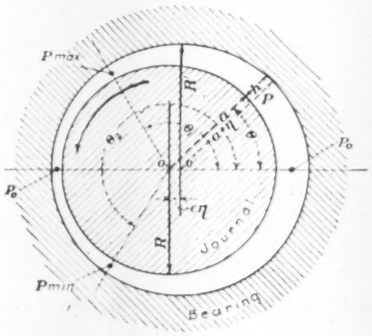


FIG. 1 JOURNAL SUPPORTING THE BEARING. THE JOURNAL PRESSES UPWARD AND THE REACTION R OF THE OIL-FILM PRESSURE IS THEREFORE DOWNWARD

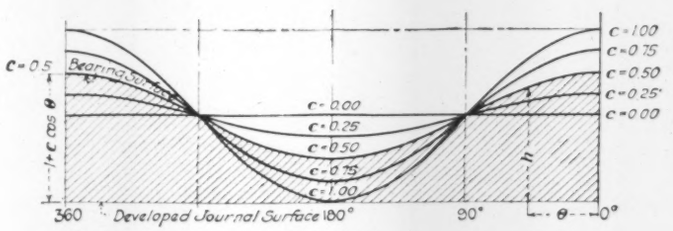


FIG. 2 SHOWING HOW FILM FORM IS RELATED TO JOURNAL ECCENTRICITY

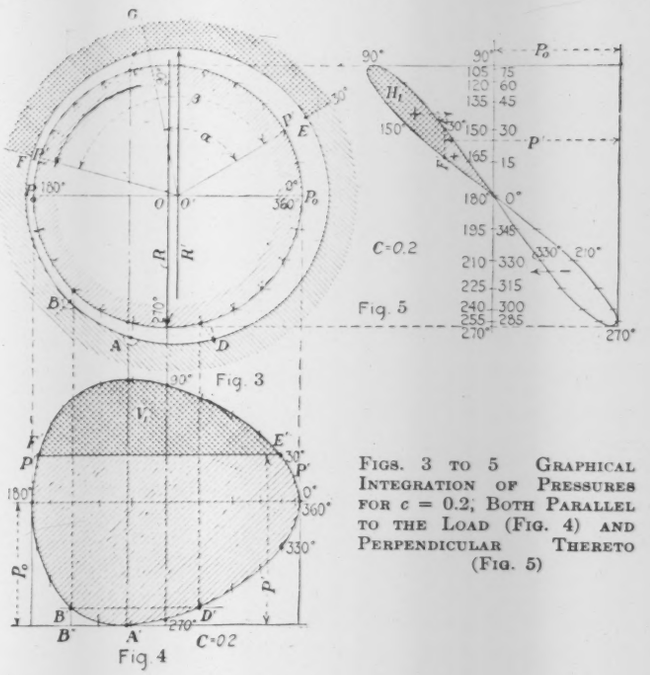
be considered first. Fig. 1, which conforms with Harrison's diagrams and symbols, shows the journal supporting the bearing. It is assumed that the journal bearing is so long that the effect of end leakage of oil is negligible. The journal revolves in the direction of the arrow with a surface velocity U. The point of nearest approach will be on a diameter perpendicular to the line of the load R, provided the oil film is continuous and completely fills the space between the journal and bearing. This has been demonstrated by both Sommerfeld and Harrison. a = radius of the journal whose center is at O. $a + \eta$ = radius of the bearing whose center is at O'. h = thickness of the oil film at angle θ from diameter through OO' and the point of nearest approach. The eccentricity OO' is expressed in terms of the radial clearance by using a factor c; thus $c\eta = OO'$. This factor c will be zero when O coincides with O'. It will be unity when the eccentricity equals η and the journal touches the inside of the bearing.

The film thickness h can be expressed quite simply by employing an approximation that is justified by the customary ratios of η/a used in practice. It is then evident from Fig. 1 that

$$h = \eta(1 + c \cos \theta) \quad \ldots\ldots [1]$$

If the surface of the journal be laid off as a straight line the relative position of the bearing surface can be drawn by plotting $(1 + c \cos \theta)$ for an assumed value of c. In Fig. 2 the bearing surfaces are so drawn for values of $c = 0$, 0.25, 0.50, 0.75, and 1.00. From this figure the relative forms of the films are clearly understood. The film for $c = 0.50$ is shown in section. If the load R is zero, c will be zero, and the film will be uniform in thickness because the centers of the journal and bearing coincide. As the load increases the eccentricity also increases, until with infinite load the surfaces touch and $c = 1$.

Referring again to Fig. 1, the pressure that is developed within the film varies from P_0 when $\theta = 0$, through P_{max} at θ_1, P_0 again when $\theta = 180$ deg., P_{min} at θ_2, and finally to P_0 when $\theta = 360$ deg.



FIGS. 3 TO 5 GRAPHICAL INTEGRATION OF PRESSURES FOR $c = 0.2$, BOTH PARALLEL TO THE LOAD (FIG. 4) AND PERPENDICULAR THERETO (FIG. 5)

The angles of maximum and minimum pressure (θ_1 and θ_2) are found from the formula

$$\cos \theta_1 = \cos \theta_2 = -\frac{3c}{2 + c^2} \quad \ldots\ldots [2]$$

Hence the positions of the points of maximum and minimum pressure are symmetrical with respect to diameter OO'; or $180° - \theta_1 = \theta_2 - 180°$.

The film pressure P for any value of θ is found from the formula

$$P = P_0 + \frac{6\mu Ua}{\eta^2}\left\{\frac{c \sin \theta\,(2 + c \cos \theta)}{(2 + c^2)\,(1 + c \cos \theta)^2}\right\} \quad \ldots\ldots [3]$$

The only new symbol in this formula is μ, the absolute viscosity of the lubricant. By making suitable assumptions for μ, U, a, η, and c, the pressures relative to P_0 can be found for all values of θ and then plotted on a polar or a rectilinear diagram.

In Figs. 3, 4, and 5 the graphical integration of pressures is shown for $c = 0.2$ both parallel to the load (Fig. 4) and perpendicular thereto (Fig. 5).

Referring to the pressure formula, Equation [3], it is evident that P_0 can have any value that will satisfy practical considerations. If an oil inlet be provided in the bearing of Fig. 3 at the

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[2] Vol. xxii, no. iii, pp. 39–54.

Presented at the Annual Meeting, New York, December 3 to 6, 1923, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Abridged. All papers are subject to revision.

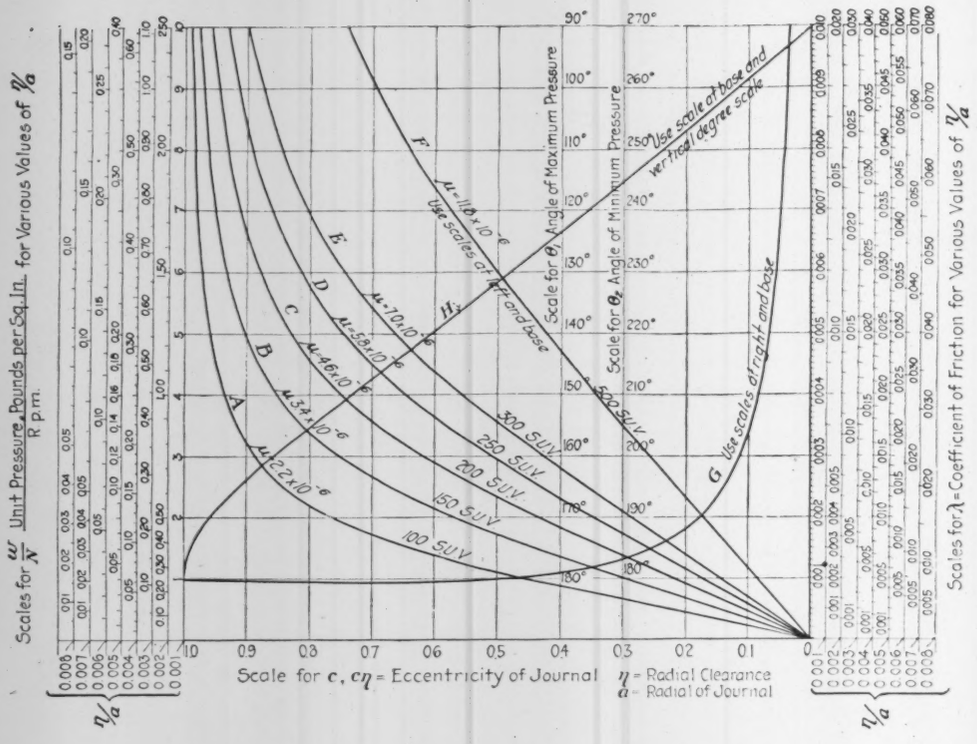

FIG. 6 CHARACTERISTICS OF JOURNAL SURROUNDED BY BEARING
($c\eta$ = eccentricity of journal; η = radial clearance; a = radius of journal. For interpretation of symbols, see Fig. 1.)

point of minimum pressure A, oil may be introduced there at atmospheric pressure, or at some other pressure determined by the oiling device. The carrying capacity of the oil film is independent of this inlet pressure so long as the film remains complete. If the oil groove is placed at some other point B, Fig. 3, it is necessary to refer to the pressure diagram, Fig. 4, on which the point B' represents the pressure. The ordinate $B'B''$ when measured by the pressure scale must be equal to or greater than the supply pressure plus absolute atmospheric pressure, because the minimum pressure at A' cannot be less than absolute zero pressure.

Two additional equations presented in the complete paper are:

$$\frac{w}{N} = \frac{\pi^2}{5}\,\mu\left(\frac{a}{\eta}\right)^2\left\{\frac{c}{(2+c^2)\,(1-c^2)^{1/2}}\right\} \quad \ldots\ldots\ldots [4]$$

$$\lambda = \left(\frac{\eta}{a}\right)\left\{\frac{1+2c^2}{3c}\right\} \quad \ldots\ldots\ldots\ldots [5]$$

in which w is the mean pressure per square inch of projected area, N the number of revolutions per minute, and λ the friction coefficient for the journal.

Equations [2], [4], and [5] appear to be the most useful for designing full bearings of this kind. A study of them is expressed graphically in the chart Fig. 6, from which the journal characteristics can be very easily determined. Curve G was plotted from Equation [5], assuming $(\eta/a) = 0.001$. Suitable scales for other values of (η/a) were then added. Curves A, B, C, D, E, and F were plotted from Equation [4], assuming $(\eta/a) = 0.001$, each curve having been drawn for the oil viscosity μ marked on it. The scales for other values of (η/a) were then added. The absolute viscosity is marked on each curve in English units—inches, pounds, seconds. The corresponding commercial viscosity as determined by a Saybolt universal viscosimeter (S.U.V.) is marked on each curve. The conversions were made from P. C. McIlheney's table as published in the *Journal of Industrial and Engineering Chemistry*, vol. 8 (1916), p. 434. A density of approximately 0.84 was assumed and the viscosities in centipoises were converted to English units by dividing by 6,900,000. For the range of viscosities illustrated in Fig. 6 the conversions from S.U.V. to absolute English units can be made with fair accuracy by means of the following formula:

$$\mu = 0.0286 \times 10^{-6} \times \text{density} \times (\text{S.U.V.} - 8) \ldots\ldots [6]$$

Data on the location of points of maximum and minimum pressure can be also obtained from the chart, Fig. 6. Curve H was plotted from Equation [2], using the c-scale at the base and the two angle scales for θ_1 and θ_2 laid off vertically near the middle of the figure.

Much interesting practical information on bearing problems can now be obtained from Fig. 6. The following examples show how it may be used. In order to avoid confusion when interpreting the readings from Fig. 6, reference may be made to Fig. 7, which shows how the angles θ_1 and θ_2 should be measured with relation to the direction of rotation and the direction of pressure of the journal upon the bearing.

EXAMPLE 1. Find the journal friction coefficient for a full bearing whose diametral running clearance is 0.001 in. per inch of diameter, if the speed is 400 r.p.m., the mean pressure 100 lb. per sq. in., and the oil viscosity is 100 sec. S.U.V.

First calculate $w/N = 100/400 = 0.25$. Then enter Fig. 6 at the left-hand vertical scale marked $(\eta/a) = 0.001$ and locate the point whose value is 0.25. From this point read horizontally to curve A, then down to the c-scale where we find $c = 0.09$, then up to curve G and horizontally to the λ scale corresponding with $(\eta/a) = 0.001$. A value of $\lambda = 0.0037$ is found. In order to determine the positions of maximum and minimum film pressure, refer to Fig. 6 again. Enter its base with $c = 0.09$ and read up to curve H and across to the scales for θ_1 and θ_2. The angles are found to be as follows: $\theta_1 = 98$ deg. and $\theta_2 = 262$ deg.

EXAMPLE 2. What clearance will give the minimum friction for a journal revolving at 1200 r.p.m. if the unit pressure is 120 lb. per sq. in. and the oil viscosity is 150 S.U.V.?

This must be solved by trial, but takes very little time. $w/N = 120/1200 = 0.1$. Assuming $(\eta/a) = 0.001$, $\lambda = 0.010$; $(\eta/a) = 0.002$, $\lambda = 0.0057$;

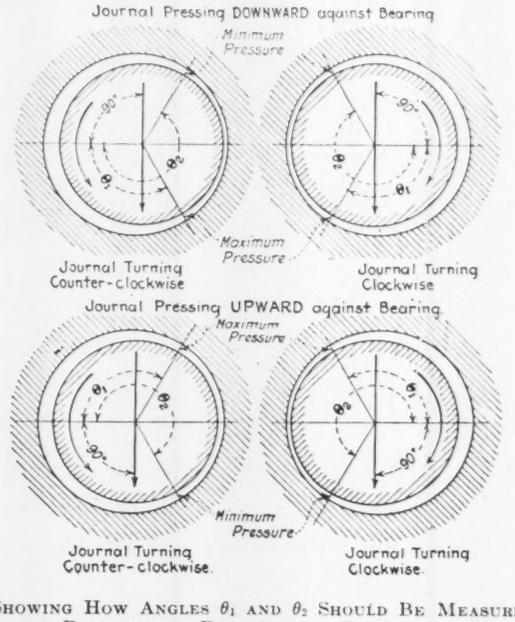

FIG. 7 SHOWING HOW ANGLES θ_1 AND θ_2 SHOULD BE MEASURED WITH RELATION TO DIRECTION OF ROTATION AND DIRECTION OF PRESSURE OF JOURNAL UPON BEARING

$(\eta/a) = 0.003$, $\lambda = 0.0037$; $(\eta/a) = 0.004$, $\lambda = 0.0039$; $(\eta/a) = 0.005$, $\lambda = 0.0048$; etc. Apparently the proper clearance is about $(\eta/a) = 0.003$. A similar problem in which $w = 60$ is plotted in Fig. 8, showing that $\lambda_{min} = 0.0057$. Decreasing the unit pressure w is thus found to increase the friction coefficient.

JOURNALS PARTIALLY SURROUNDED BY THE BEARING

Tower ran his experiments on a bearing partially surrounding its journal. Hence when Professor Reynolds made his analysis

of these experiments he investigated the case of a journal partially surrounded by its bearing. His work, as previously stated, is not simple enough to be easily used by others. Sommerfeld later made an analysis of a journal completely surrounded by its bearing and also of one in which the bearing extended exactly half-way around. W. J. Harrison later solved the problem of the complete bearing in a simple manner which can be readily used. Harrison's work on the complete bearing also forms the basis of the following study of partial bearings.

An examination of the differential equations from which the pressure Equation [3] is obtained shows that the integration proceeds from the point of maximum pressure and ends with the point of minimum pressure. It appears that this integration can be stopped off anywhere around the film provided only that the pressures at the two ends of the film are such as can readily exist in a bearing. The simplest case is where the pressures are the same at both ends of the film and are atmospheric.

When dealing with partial-bearing films the conditions of equilibrium must be carefully examined to determine the direction of the resultant pressure upon the bearing. The process by which partial bearings can be studied will be evident from the following comments upon Figs. 3, 4, and 5. It may be assumed that the bearing begins where $\theta = 30$ deg., i.e., at point E in Fig. 3, and that the pressure at that point is P'. We must first determine the next point in the direction of rotation of the journal in which the pressure is the same as at 30 deg. Referring, therefore, to the points E' in Figs. 4 and 5, corresponding with point E in Fig. 3, the lines $E'F'$ may be drawn parallel with the zero-pressure axis and cutting the closed pressure loop at F'. The pressure at both E' and F'

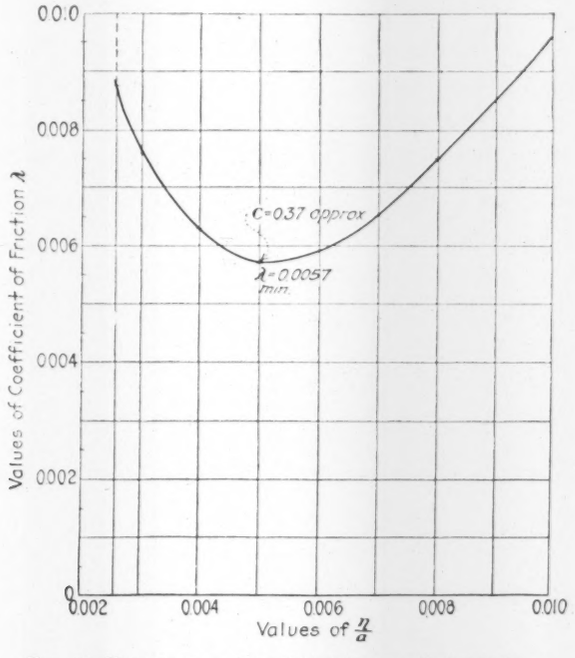

FIG. 8 VARIATION OF λ WITH (η/a) FOR A SPECIFIC CASE
[Example data: $N = 1200$; $w = 60$; $\mu = 3.4 \times 10^{-6}$ (S.U.V. = 150).]

will be P'. The point F' in Fig. 4 or Fig. 5 may be transferred so as to locate point F in Fig. 3. This may therefore represent the end of the partial bearing that begins at E which is 30 deg. from the diameter that is perpendicular to the load. The angular length of the partial bearing is β.

If we shade again the portion of the pressure loop lying above the line $F'E'$ in Fig. 4, this double-cross-hatched section will represent the vertical component V_1 of the film pressure between the partial bearing EF and the journal.

Referring now to Fig. 5, if we again cross-hatch the portion of the loop at the left of $E'F'$, this double-cross-hatched section represents the horizontal component H_1 of the film pressures between the partial bearing EF and the journal. This acts to the right on the journal and to the left on the bearing.

The relative magnitudes of V_1 and H_1 can be determined by measuring the double-cross-hatched areas with a planimeter. The resultant of these two will act along the line $O'G$ in Fig. 3 at angle α from $O'E$. This line of resultant pressure will divide the partial bearing β into two portions, α and $\beta - \alpha$, the portion α representing the leading portion and the remainder the trailing portion when the bearing is considered with reference to the direction of rotation of the opposing journal surface.

The method outlined above has been applied to the examination

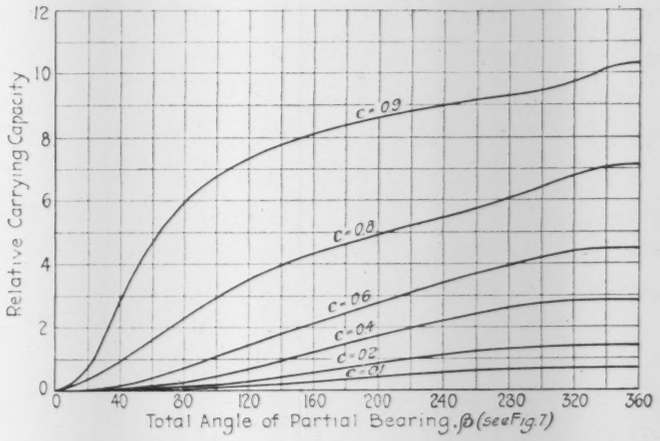

FIG. 9 RELATIONS BETWEEN BEARING ARC β, ECCENTRICITY, AND CARRYING CAPACITY

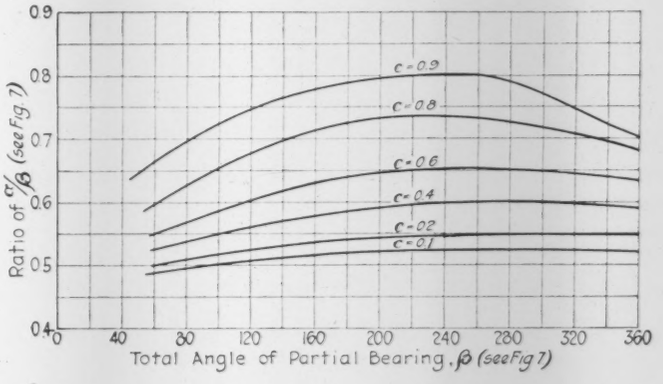

FIG. 10 LOCATION OF APPLIED LOAD WITH RELATION TO BEARING ARC β

of partial journals varying in arc from 0 deg. to 360 deg. for various values of the eccentricity c. The results thus far obtained are indicated by Figs. 9 and 10; the first showing the relation between bearing angle, eccentricity, and carrying capacity; the second the location of the applied load with relation to the bearing arc β.

The investigation of partial bearings is being continued and it is expected that the results can be charted in as useful a manner as those in Fig. 6. This work will probably be completed before the coming spring.

Discussion

G. H. MARX[1] criticized the work of A. Sommerfeld and W. J. Harrison, on which Mr. Howarth's paper is based, as erecting a mathematical theory based on insufficient experimental data, and including assumptions contrary to assumed facts. For example, in the investigation at Stanford University of the oil-films of complete cylindrical bearings with ring oiling, in no case did the point of nearest approach lie at right angles to the line of pressure, and in every case the center of the journal was lifted above the center of the bearing while the load was directed vertically downward.

A. R. Roberts[2] laid stress on the possibility of subatmospheric pressures in the film and its consequent possible rupture. Such a condition would account for discrepancies between theory and experiment. The facts that in a full bearing the axis of the journal

[1] Prof. Mech. Design, Stanford University, Cal. Mem. A.S.M.E.
[2] Assoc. Prof. Mech. Eng., McGill University, Toronto. Mem. A. S.M.E.

moves relatively to the axis of the bearing in a straight line along the diameter at right angles to the load line and that the point of minimum film thickness is always at the end of this diameter, while in the half bearing, according to Sommerfeld, the axis of the journal moves in a curved path, may introduce errors in the author's treatment of the half-bearing. But the discrepancies are not serious.

A. E. Flowers[3] advised caution in the use of Dr. McIlheney's tables for viscosities, which are partially unreliable owing to discrepancies in viscosimeter readings. He also pointed out that increase in load above usual operating conditions might increase the temperature, decrease the viscosity, and in turn increase the friction. This cumulative effect is dangerous, and in practical design a continuous heat-dissipating capacity equal to the friction heat energy should be provided.

Mayo D. Hersey[4] pointed out that in the light of a paper presented by D. P. Barnard, 4th, and co-authors, before the American Chemical Society (Sept., 1923), the author's theory might not apply for values of $\frac{\mu N}{w}$ below those corresponding to the minimum coefficient of journal friction. For higher values of $\frac{\mu N}{w}$ the author's theory while correct, seemed unnecessarily complex to Mr. Hersey. It was sufficient, in these ordinary high-speed problems, to work with the simple formula of the concentric bearing. At high speeds, moreover, it was difficult to predict what the true viscosity of the oil film would be. The author's results here again were mathematically correct, but they presupposed a knowledge of that unknown viscosity. Suggestions for determining this coefficient of friction when thermal equilibrium had been reached, without knowing the true temperature or viscosity of the film, were to be found in a paper written by Mr. Hersey and published in the November, 1923, issue of the *Journal of the American Society of Naval Engineers*.

Messrs. Daniel P. Barnard, 4th,[5] and E. V. Murphree[5] emphasized the following facts: (1) The variable pressure in the oil film is independent of the oil-feed pressure; (2) the position of the journal in the bearing, and consequently its carrying power, is independent of the oil-feed pressure beyond that necessary to insure an unbroken supply of lubricant; (3) while the optimum position for the oil hole is at the point of minimum pressure, ordinary bearings do not follow closely the laws of the two-dimensional theory. Lacking data as to the location of the point of minimum pressure, it is as a rule safer to place the oil-supply hole at a point which is located on the low-pressure side in line with the application of the load.

Messrs. Barnard and Murphree also pointed out that the two-dimensional theory in which the distribution curve for the variable oil-film pressure is taken as symmetrical to the displacement axis, so that direction of displacement of the journal must be at right angle to the applied load, leads to the conclusion that if the actual minimum pressure should tend to drop below a value of zero absolute, a rupture of the film must occur. In the interpretation of considerable experimental data, the two-dimensional concept leads to the evaluation of such a pressure as -27 lb. per sq. in. and in one case of -154 lb. per sq. in. Such pressures cannot exist in a liquid film and their apparent presence indicates a discrepancy between fact and theory. Three-dimensional analysis by the writers has to some extent removed the discrepancy on the following lines of argument: (1) The distribution curve for the variable pressure is not symmetrical to the displacement axis; (2) for a short bearing the displacement of the journal is *not* at right angles to the load; (3) the maximum positive variable pressure in the oil film is ordinarily much greater than the corresponding negative pressure. Conclusion (3) accounts for the possibility of existence of "negative" pressures in an ordinary bearing, and at the same time precludes any chance for predicting by calculation the point of film rupture. That this conclusion must be true is obvious when it is realized that the ends of the conventional bearing are exposed to atmospheric pressure and that the existence of a pressure below this figure will cause flow *inward* toward the center of the bearing.

W. Elmer[6] discussed the problem of lubricating crankpins. Locomotives have become so large and the limit of the clearance sideways is so definite that the pressures on the crankpin have reached a point where they cannot be lubricated satisfactorily. With a particular engine where the pressure exceeds 2000 lb. per sq. in. trouble is quickly experienced on the first two or three miles of a grade. Hard grease does not seem to solve the problem.

W. E. Simmons[7] emphasized the tremendous importance of lubrication in railway work and the lack of solution thus far. He criticized the paper as not giving formulas which could be immediately and readily utilized.

James A. Hall[2] showed that the lubrication problem in the machine-tool industry was the exact opposite of that in railway engineering, in so far as it involved to a large extent very light loads and high speeds. Under normal operating conditions with a grinder having a spindle 2 or 3 in. in diameter and a speed of 1500 r.p.m., with clearances of one-thousandth or one-thousandth and a half, even using the thinnest lubricants possible, the charts of Mr. Howarth's paper would not extend to take in such conditions, and there would be a possibility of very large coefficients of friction. Another point which was raised by Mr. Hall in his discussion was that in practice with bearings with very small clearance, the more oil used up to a certain point, the hotter the bearing would run.

W. T. Magruder[8] pointed out the fallacy of considering truly straight cylindrical bearings. The presence of deflection curves in shafting vitiates theoretical considerations of lubrication.

In closing the discussion, the author, H. A. S. Howarth, stated that the paper was only the beginning of a study whose completion might be expected at the next Annual Meeting. The experiments would include tests on a shaft of very high elastic limit on two journal bearings, placed on either side of the experimental bearing, with the experimental bearing lubricated in different ways and subjected to as heavy loads as the shaft would carry. The theory presented thus far was not to be regarded as final, and might be modified with the accumulation of experimental data. Replying to Professor Marx's criticism, Mr. Howarth questioned the validity of his experimental results which were obtained from students' theses. In answering Mr. Elmer on the subject of locomotive crankpins, he pointed out that when grease is used there is no proper flow of a lubricant through a film, but intermittent squeezing and smearing of the grease on one side and the other of the pin. In regard to railway journals, Mr. Howarth understood that on a locomotive they still used an oil groove at the top of the bearing, and therefore divide the journal of the locomotive axles into two parts, one of which is working against the other. Poor lubrication must necessarily be the result. In regard to the point raised by Mr. Hall that in running with very small clearance, when oil is put in at a low rate, there is low friction; and when the rate of oil is increased, there is higher friction, Mr. Howarth stated two causes. With the small rate of oil supply there is not much cooling effect, consequently the film runs hotter and the viscosity of the oil is perhaps rather high. A more satisfactory explanation is perhaps that with a very small oil supply the lubrication is one of air and oil, whereas if enough oil is put in to have a complete oil film, the viscosity of oil has to be considered and the bearing no longer runs partially on oil. In answering Professor Magruder on the deflection of shafts, Mr. Howarth stated that it all came down to the relation between the deflection of the shaft and the thickness of the film in the bearing. If the deflection of the shaft is a reasonably small proportion of the thickness of the film on the loaded side, the bearing will work well. If the shaft is overloaded, the film in the middle will be good, but one end of the bearing may be rubbing. Long bearings are almost a thing of the past, and it is surprising what loads can be put on bearings, and how short they can be made. The problem of deflection then disappears.

[3] Development Engr., De Laval Separator, Poughkeepsie, N. Y. Mem. A.S.M.E.

[4] Bureau of Mines, Pittsburgh, Pa. Mem. A.S.M.E.

[5] Massachusetts Institute of Technology, Cambridge, Mass.

[6] Supt. East. Lines, Middle Div., Pa. R.R. Co., Altoona, Pa. Mem. A.S.M.E.

[7] Providence, R. I. Mem. A.S.M.E.

[8] Prof. Mech. Eng., Ohio State University, Columbus, Ohio. Mem. A.S.M.E.

Progress in Steam Research

Reports of Results Obtained in the Harvard Experiments—Work Well Under Way at M.I.T. and the Bureau of Standards

THE second annual session on Progress in Steam Table Research attracted a group of over eighty interested scientists and engineers to hear the results of the valuable studies now being made in regard to the properties of steam at high pressures and temperatures. This session was held on Wednesday afternoon, December 5, during the recent Annual Meeting of the A.S.M.E.

Dr. A. M. Greene, Jr., of the Steam Table Fund Executive Committee, presided at the session, at which progress reports were presented by N. S. Osborne and H. F. Stimson of the Bureau of Standards, F. G. Keyes of Massachusetts Institute of Technology, and Harvey N. Davis and R. V. Kleinschmidt of Harvard University. These were followed by a general informal discussion. Geo. A. Orrok, Chairman of the Executive Committee of the Steam Table Fund, presented a brief report of the Fund, and at the close of the meeting briefly summed up the results of the work. Mr. Orrok's remarks and the reports of the investigators are given in abstract below.

Report of Executive Committee of Steam Table Fund

THE work under the Steam Table Fund has been progressing during the past year, as will be seen from the reports submitted by the investigators. The subscriptions stand roughly as they did last year, at about $28,000. Of this sum, as of November 21, 1923, $17,201.34 has been collected and our expenditures have totaled $14,618.73, leaving a balance of $2,582.61 on hand in the Society's custody.

Of the amount disbursed $68.79 has been expended at the Society headquarters, $9,204.87 at Harvard University, $3,282.57 at the Massachusetts Institute of Technology, and $2,062.50 at the Bureau of Standards. Collections are coming in and enough money is in sight to carry on the work for at least another six months, which will include all our obligations up to date. Besides this we have been presented by Mr. Chas. A. Brown, of Chicago, with a high-pressure Winslow boiler which will enable us to carry our work to pressures of 1200 to 1500 lb.

Your Executive Committee have been in close touch with the experimental program and actual results are now in sight, although much work remains to be done. Further subscriptions will probably be necessary and measures are under way to secure such additional funds as may be needed to carry on the work to its ultimate end.

Report on Progress in Steam Research at the Bureau of Standards[1]

By N. S. OSBORNE[2] and H. F. STIMSON,[3] WASHINGTON, D. C.

THE principles of the experimental method of surveying the behavior of steam have been explained in a previous communication.[4] The first tentative design of a calorimeter for this purpose was developed with special regard for the requirements as to what it must accomplish, leaving many of the practical details of construction to be dealt with later.

The design of the central or main element of the apparatus is illustrated in Fig. 1. The purpose of the inner shell is to isolate a specimen of water from other bodies so that we may accurately account for the amount of water and its state, the energy added as heat, and the work done. It is proposed to make the series of three types of experiments leading to the determination of the group of thermal properties of saturated water or steam over the range of temperature from 32 deg. fahr. to 572 deg. fahr., and the corresponding range of pressures up to about 80 atmos.

The calorimeter shell is built of two hard-drawn cups of an alloy of 80 per cent copper and 20 per cent nickel. To protect it from action of the water the shell will be gold plated. The joint is sealed by a gold gasket compressed in a groove under a close fitting tongue by means of a double-threaded band or nut. The shell will hold about one pound of water at 212 deg. fahr. Tubes of resistal steel support the shell and withdraw vapor or liquid. Ability to account for the heat added depends upon the thermal insulation of the shell. By enclosing it within another shell or envelope whose temperature is controlled and evacuating the intervening space, transfer of heat to and fro may be kept under control. The envelope is to be kept at the same temperature as the calorimeter shell surface, thus annulling thermal leakage.

A centrifugal pump within the calorimeter lifts the water to the top and circulates it rapidly over the entire inner wall of the shell. Some overflows and bathes an electric heating coil. Measured energy may be added to the system through this heater, which operates both as heater and evaporator. The nearer the source of heat to the free surface of liquid, the less equilibrium is disturbed in getting the heat where it is absorbed in evaporation. Quiet evaporation is favored and wet vapor avoided.

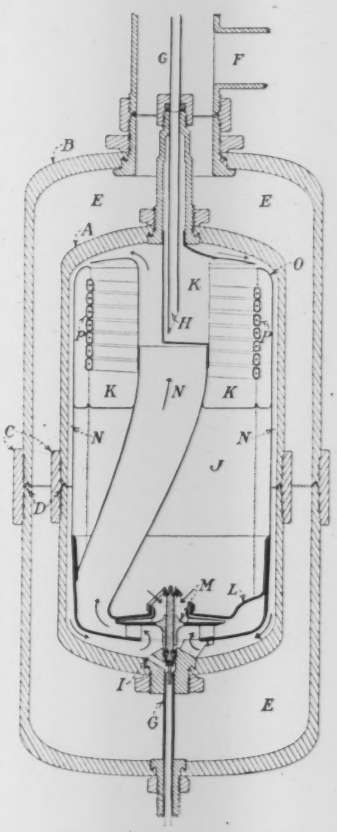

FIG. 1 SECTIONAL VIEW OF CALORIMETER

(*A*, calorimeter shell; *B*, envelope shell; *C*, right-and-left-threaded band; *D*, gold gasket; *E*, vacuum space; *F*, tube for exhausting; *G*, tubes to support shell and transfer water; *H*, vapor outlet; *I*, liquid outlet; *J*, liquid space; *K*, vapor space; *L*, centrifugal-pump casing; *M*, double impeller; *N*, flow channels for water; *O*, overflow port; *P*, gauze-covered electric heater or evaporator. The envelope shell *B* is roughly 4 in. in diameter and 9 in. long.)

The pump circulates about six quarts of water per minute, the equivalent of the entire contents passing around every five seconds. The circuit divides at the top, part following the wall of the shell and part overflowing and bathing the evaporator. To circulate the two streams, one of large volume and low head, and the other of small volume and greater head, the pump wheel is made in two parts rotating together and delivering into the same casing. The combination in parallel of two stages, of different characteristics, gives excellent heat distribution with little power.

The power used in the pump remains as heat and makes power waste objectionable. As a pump the design is not remarkably efficient. However, as it imparts but 0.03 watt to the water its moderate efficiency of 25 or 30 per cent ought not to be compared with 80 or 90 per cent for pumps millions of times more powerful.

Three stages in developing the pump are shown in Fig. 2. Tests of these models showed limitations inherent to the size and service, and it was found necessary to employ an unusual combination to get adequate circulation with the allowable power. The method of testing model pumps is shown in Fig. 3. Speed and torque gave input, and lift and delivery the output.

The evaporator has been the subject of experiment in its development and test. A resistance wire is embedded in clay in a flattened gold tube wound into a helix. This tube is covered with fine metal gauze to keep the surface wet. Water flows in a thin film over the whole surface, and is led quietly off by a gauze apron. A model of appropriate size evaporated water quietly at a rate of

[1] Communicated by the Director of the Bureau of Standards.
[2] Physicist, U. S. Bur. of Standards.
[3] U. S. Bur. of Standards.
[4] See page 88 of this issue of MECHANICAL ENGINEERING.

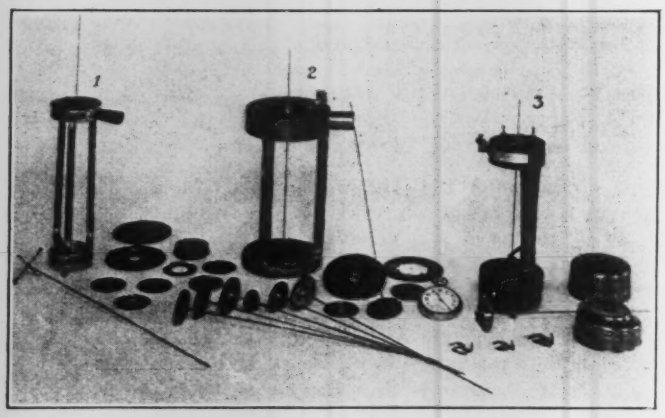

FIG. 2 MODELS OF EXPERIMENTAL PUMPS BUILT AND TESTED
(1—First rough model. 2—Second model, carefully built, with various forms of impellers and diffusion rings. 3—Third model with special features for calorimeter duty; speed, 900 r.p.m.; output, 1/28,000 hp., efficiency, about 28 per cent.)

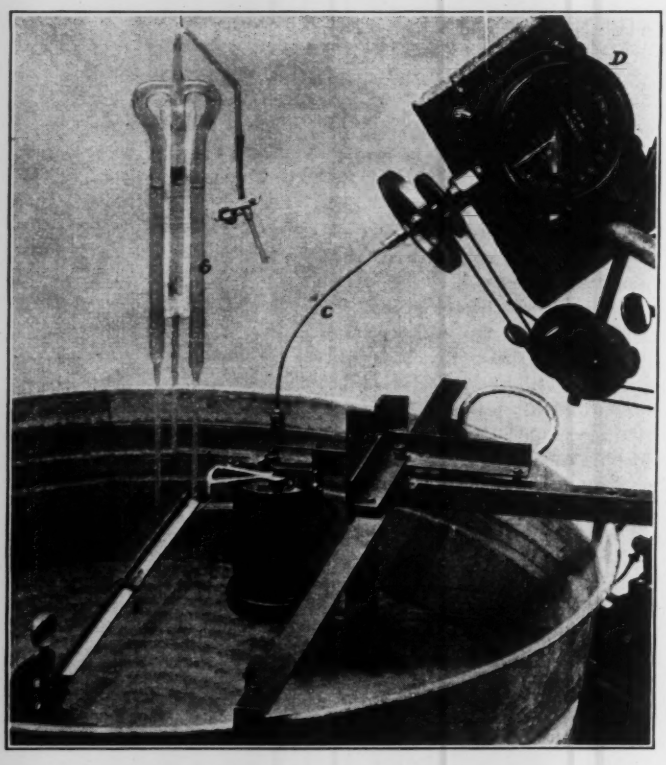

FIG. 3 SET-UP FOR TESTING PERFORMANCE OF MODEL PUMPS
(*A*, model pump; *B*, water reservoir; *C*, flexible drive shaft; *D*, tachometer; *E*, spring dynamometer; *F*, torque arm; *G*, gage for indicating lift of either stage; *H*, receiver with port for delivering the water pumped.)

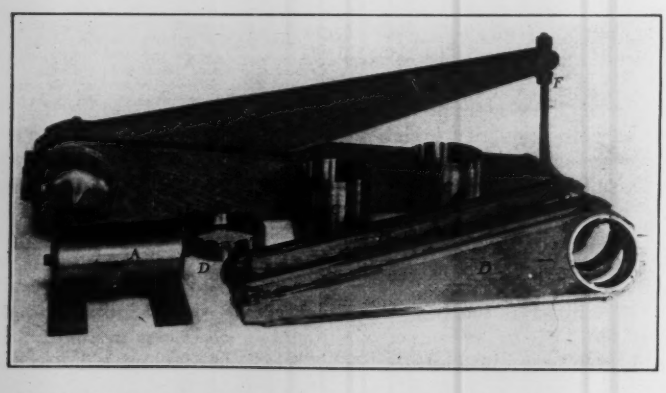

FIG. 4 METHOD OF ASSEMBLING CALORIMETER AND ENVELOPE SHELLS
(*A*, 3-in. calorimeter shell, assembled; *B*, wrenches for calorimeter shell; *C*, parts of 4-in. envelope shell, *D*, right-and-left-threaded band for 4-in. shell; *E*, manner of using wrenches for setting up joints; *F*, screw for driving wrench.)

10 grams per minute, using about 400 watts. Of course, it is unnecessary to use so high a rate of evaporation as this to give appropriate quantities for accurate measurement, but additional capacity gives a wider range of experimental conditions which can be used to study and eliminate effects of various sources of error.

The construction of a metal shell suitable for confining fluid at 572 deg. fahr. and 1200 lb. per sq. in., in which the equipment described may be assembled, is of some interest. The shell must be elastic, hence annealing by brazing is objectionable. Ability to clean all enclosed parts and protect them from the action of water at high temperature is important. The manner of assembling the shell and setting up the holding band with a special wrench so that the tension in the band will resist the interior pressure and still maintain the tightness of the gold seal is shown in Fig. 4.

For measuring the temperature, resistance thermometers and thermocouples furnish an elegant and trustworthy means which is especially adapted for installation in the surroundings of our apparatus. Thermometers will be placed in a receptacle in the thermo-regulated bath surrounding the envelope. This receptacle will damp out fluctuations and take a steady temperature which may be accurately observed by the thermometers. The difference between this reference temperature and the temperature of the calorimeter will be observed by means of thermocouples. Four resistance thermometers of special design have been made and their constancy and reliability are being studied.

A few typical examples of interesting features of the design which still require study are: bearings suitable for a pump shaft running at 1000 r.p.m. in water at 572 deg. fahr. for long periods without deterioration or attention; an absolutely tight and dependable stuffing box for the pump drive shaft; a device for controlling the rate of vapor withdrawal; an accurate temperature-control system operating up to 572 deg. fahr.; material and form of control valves to work perfectly and avoid loss or contamination of water; etc. The variety, number, and character of these tributary problems might well discourage the undertaking but for the exceptional resources which favor it at the Bureau of Standards.

On the assumption that mechanical engineers will not be finally satisfied without a complete and trustworthy survey of the behavior of saturated steam, no attempt has been made to temporize by crowding the experimental program, and it is hoped the profession will appreciate and indorse this policy of thoroughness.

Progress of the M.I.T. Portion of the Steam Investigation[1]

BY FREDERICK G. KEYES,[2] CAMBRIDGE, MASS.

THE report of progress presented in March of this year sketched very briefly the method by which the pressure, volume, and temperature relations for saturated and superheated steam were to be measured. Since that time the entire apparatus has been completed, assembled, and calibrated in part. In this report the description of the method will be presented in some detail, together with photographs of the actual apparatus.

The container for the steam under measurement should be preferably of a homogeneous piece of metal capable of resisting the chemical action of water at all temperatures up to 900 deg. fahr. It will be of material assistance if at the same time the metal will not amalgamate with mercury.

The metal chosen for the bomb is pure nickel, as stated in the last report. The forging is of about 99 per cent nickel,[3] hollowed out to a volume of some 220 cc. Closure is effected by a piece of nickel resting against a nickel gasket which has been held for some time at 2300 deg. fahr. in a stream of pure dry hydrogen. This treatment gives a very soft metal which appears to be very suitable.

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[1] The work is being carried out in collaboration with Dr. L. B. Smith and Dr. S. S. Taylor, research associates attached to the staff of the Research Laboratory of Physical Chemistry.

[2] Research Laboratory of Physical Chemistry, Massachusetts Institute of Technology.

[3] The analysis has not been completed at the time of this writing. Acknowledgment is made of the Research Laboratory's indebtedness to Mr H. I. Cole of the International Nickel Co. for his aid in providing special pieces of nickel and monel metal needed in constructing the apparatus.

The total volume of the bomb is obtained by weighing the amount of mercury required to fill it at a definite temperature.

The bomb is connected to the volume- and pressure-measuring portions of the apparatus by means of nickel tubing of 0.025 in. bore and 0.090 in. outside diameter, provided by Mr. Philip Dorticos, of the Edison Lamp Works, Harrison, N. J.

The volume-measuring device, Fig. 5, consists of a cylinder provided with packing gland and a 12-in. by $^5/_8$-in. piston of steel driven by a screw and nut. Special roller bearings receive the thrust. The nut is of a single piece of tobin bronze, the lower periphery being marked with 100 divisions. A counter registers the number of whole turns, while the fractions may be estimated on the engraved nut to 0.001 turn. The screw has 18 threads per inch, cut in such a shape as to present a flat surface to the thrust instead of the usual V-thread. A brass tube is placed over the projecting portion of the thread for protection.

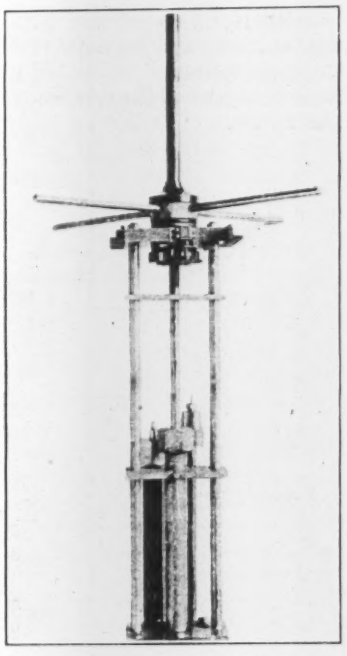


FIG. 5 VOLUME-MEASURING DEVICE

The calibration of the piston displacement and thread is obtained by exhausting the piston cylinder and filling it with mercury. The amount of mercury ejected for each successive five turns of the screw is then weighed, and from the known density of the mercury the volume is computed at the temperature (86 deg. fahr.) at which the cylinder and piston are maintained in the bath represented in the diagram, Fig. 6. Fig. 7 shows the volume-displacement apparatus set in position and the bath in which it is immersed.

The apparatus for measuring the pressures is of the dead-weight type, but of the design evolved in the course of the last 12 years' experience in pressure measurements. It is shown in diagram in Fig. 6 and may be recognized in Fig. 8 to the left. It consists of a hardened-steel piston $^3/_8$ in. in diameter, lapped to the proper fit in a hardened cylinder. It is oscillated continually during use by means of a motor and mechanism in order to obviate static friction. The

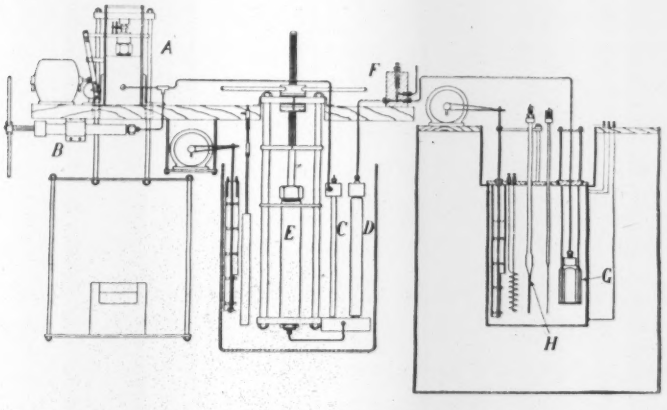


FIG. 6 DIAGRAM SHOWING DISPOSITION OF APPARATUS

oil injector used to make up for oil leakage around the pressure piston and to float the piston is shown at *B*, Fig. 6.

The constant-temperature bath for the steam bomb is shown at the right of Fig. 6. It consists of a 10-in. Shelby tube 18 in. in length with a welded bottom. The outside of the bath is wound with special ironclad nichrome-wire electrical resistance heaters. The bomb is supported in a holder shown at *G*, Fig. 6, and may be seen in Figs. 7 and 8 resting on the top of the bath. The photographs show the galvanized-iron can in the center of which the bath itself is located. The can serves to hold the insulating material.

The liquid employed in the present bath is designed for the range 350–900 deg. fahr. and is a mixture of sodium and potassium nitrates. It is a liquid at about 350 deg. fahr. and stirred as indicated in Fig. 6. The automatic maintenance of a definite temperature is secured by means of a device[1] based on utilizing the deflection of a galvanometer in a Wheatstone bridge balanced at the desired temperature and one arm of which consists of a 200-ohm pure nickel resistance element contained in a one-piece flat tube

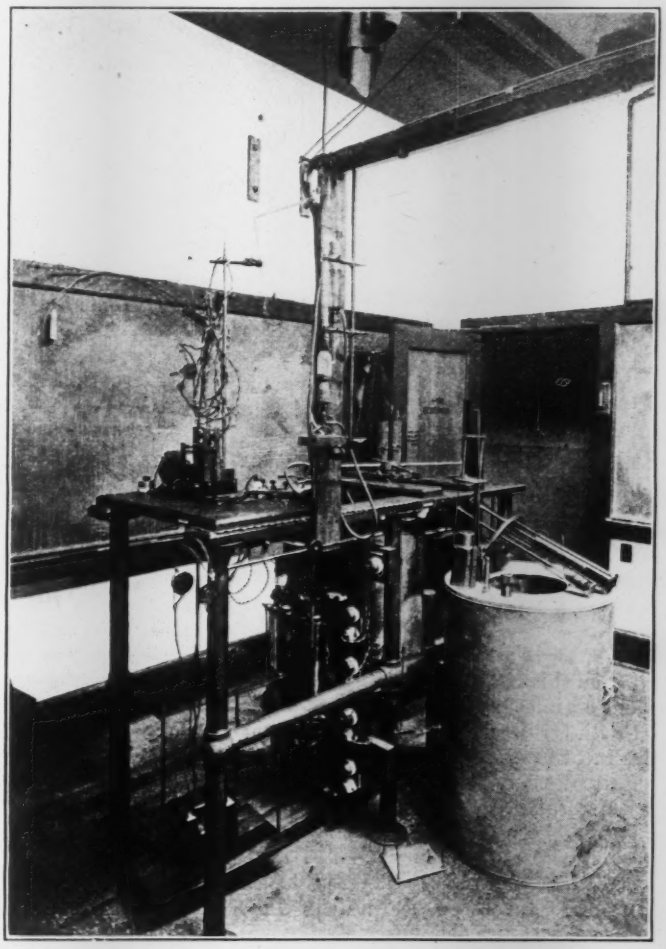


FIG. 7 VOLUME-DISPLACEMENT APPARATUS SET IN POSITION AND THE BATH IN WHICH IT IS IMMERSED

H, Fig. 6. The details of this circuit are shown in Fig. 9, in which 4 represents the nickel-wire element *H* of Fig. 6. The bridge arrangement is known and resistances 1, 2 and 3 may be adjusted to suit the temperature setting desired in the bath containing the bomb *G*, Fig. 6. The galvanometer *Ga* is provided with an arrangement whereby when the needle deflects, the circuit of the battery *C* is completed, charging the grid *G* negatively and thus interrupting the current flow between the filament *F* and plate *P*. When the circuit of battery *C* is open current flows from *F* to *P* through the 12,000-ohm relay *R*, which in turn completes the circuit through the temperature-regulating heater resistance *H*. The relay *R* may be obtained from the Western Electric Co. and operates on 0.002 ampere.

Returning to Fig. 6, the functioning of the apparatus may be sketched. The water, entirely permanent-gas-free, is contained in the steel bomb *G*. A fine-bore (0.025 in.) nickel tube connects the bomb to the shut-off block *F*, and therefrom connection is completed by means of nickel tubing to the cylinder *D*. The latter is part of the volume-measuring device *E*. Parallel to and a part

[1] The author and his associates are greatly indebted to Prof. John R. Roebuck of the University of Wisconsin for certain ingenious details of this apparatus and also for a supply of the pure nickel wire contained in the element *H*.

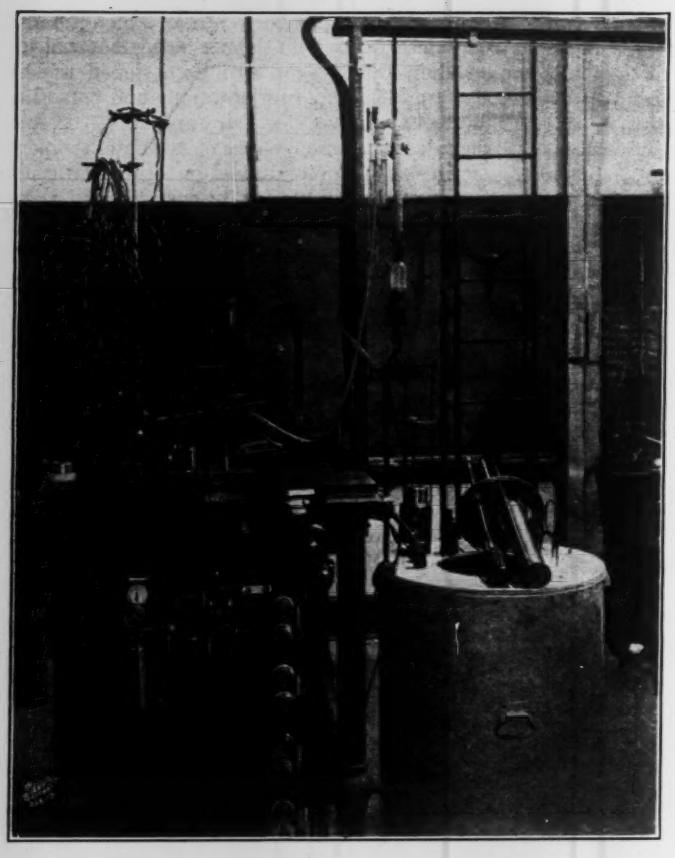


FIG. 8 ANOTHER VIEW OF THE APPARATUS SHOWN IN FIG. 7

of the latter is a riser C carrying an insulated needle at the top, and from this riser connection is made by the oil line to the gage A and oil injector B. The volume-measuring cylinder E, riser C, and cylinder D are kept at the constant temperature of 86 deg. fahr. in the automatically regulated bath indicated in the diagram.

For many substances it is possible to confine the material under measurement in the bomb by means of mercury. This procedure is impossible where the measurements are required below the freezing point of mercury (−38.0 deg. fahr.) and much above 350 deg. fahr. The procedure is in this case to confine the material with itself. In consequence G is completely filled with water during all measurements except when the vapor pressure is under measurement. The water also fills the nickel capillary through block F, finally coming in contact with mercury contained in D in the 86 deg. fahr. bath. The mercury completely fills E and D to the point of contact with the water in the latter. The mercury is present in the riser C up to the point of contact with the insulated needle, and makes connection with the oil line leading to the pressure gage. By means of the oil injector B it is at all times possible to hold the oil level just in contact with the mercury at the needle point. The indication of the latter is given by means of an electrical circuit involving a telephone which is excited when contact is made.

It is now evident that there are two masses of water present: A large quantity at G where the temperature is maintained anywhere in the range of temperature desired in the measurements and in D maintained always at 86 deg. fahr. The very small quantity of water in the connecting nickel capillary is at a variable temperature and its temperature obtained by means of a number of thermocouples. The portion of the capillary just at the exit of the bath containing G is surrounded with a jacket containing running water in order to make as abrupt a change in temperature as possible and to facilitate the location of the water meniscus in measurements wherein G contains the vapor phase only.

The volume of G is known accurately, as well as the total mass of water contained in the system as a whole. When the bath containing G is at 86 deg. fahr. all the water (excepting a small amount contained in the nickel capillary whose mean temperature is obtained by the thermocouple) is at one temperature, and by measuring the pressures for definite settings of the volume-measuring piston the compressibility of water at 86 deg. fahr. can be very accurately obtained. These data are needed in order that the mass of water contained in D may be known at all pressures. The water in G may now be brought to any temperature desired and the mass of water obtained as the difference between the total quantity placed in the apparatus and that in the cylinder D. The system may be designated as one wherein the volume is constant but the mass of water under measurement is variable at will.

In the measurements on the saturation liquid-phase volumes and some of the vapor pressures, the bomb G is full of water in the liquid phase. For the measurements in the superheat smaller total quantities are used, but D and the nickel capillary are of course at all times filled with liquid water at 86 deg. fahr.

At the present moment the calibration of the bomb G is being completed and its stretch with pressure determined. The first measurements will be those of the saturation liquid volumes and the vapor pressures to the critical temperature. The most time-consuming part of the program will be the exploration of the superheat region.

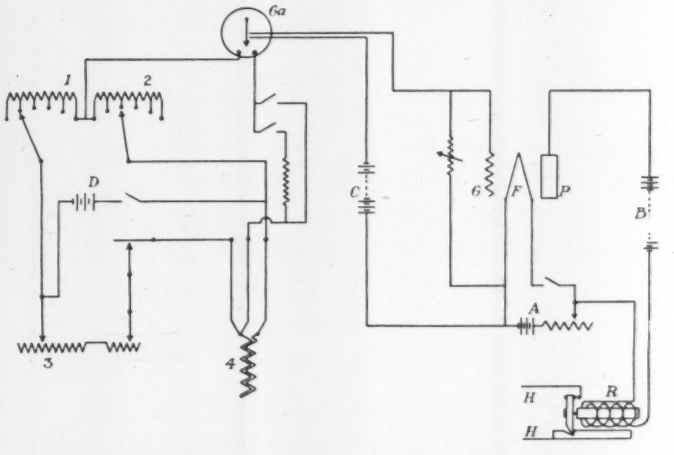


FIG. 9 DETAILS OF CIRCUIT OF DEVICE FOR AUTOMATICALLY MAINTAINING A DEFINITE TEMPERATURE IN THE BATH

Progress Report on Work at Harvard University on the Joule-Thomson Effect

BY R. V. KLEINSCHMIDT,[1] CAMBRIDGE, MASS.

A YEAR AGO at this meeting the speaker gave some preliminary values for the Joule-Thomson effect in superheated steam.[2] The portion of the work being carried on at Harvard University is entirely confined to the superheated region at relatively low pressures; that is, actual measurements have been made from 50 up to nearly 600 lb. per sq. in.

The apparatus employed has been very considerably changed in detail, but not at all in general form. As noted with some detail last year, the steam is generated in a gas-fired, automatically controlled boiler and then led through a primary superheater and steam separator. It is then passed through an alundum porous plug, where the pressure drops some 15 or 20 lb. per sq. in. The steam then passes into a countercurrent drier, and after having been heated to a high temperature and then cooled again, passes through another porous alundum strainer, on which is wound a coiled resistance wire which superheats the steam to a certain extent. By controlling the voltage on this coil the temperature of the steam entering the bath may be regulated to any accuracy desired.

One of the improvements made since the last report is in the mechanical details of the plug case. This was formerly a piece of 5-in. steel pipe with two screwed heads, one on each end, through which the various connections were made, and great difficulty was experienced in keeping these tight at high temperatures and pressures. The new plug case is formed out of a solid piece of steel, except the top

[1] Research Fellow, Harvard University.

[2] MECHANICAL ENGINEERING, March, 1923, p. 165.

head, which is bolted on with six strong bolts and has a corrugated male and female joint in which an asbestos gasket is placed. This joint has been tightened and tested to 1350 lb. without a leak; then heated up and tested again, when it began to leak at 1200 lb. pressure and stopped on the way down at 750 lb. It was then tightened still more, tested up to 1200 lb. without a leak, and put in the bath. So far as is known, it has not leaked since. But leakage was one of the great difficulties experienced in the earlier work and gave results that were about one per cent too low.

The thermostat employed in the bath is a mercury one, and, as suggested by Dr. Keyes, a long capillary is used to gain some pressure on the mercury and permit running up almost to the boiling point of mercury, the apparatus being designed to run at about 1650 deg. fahr. It has actually been run satisfactorily at that temperature, but no oil has been found that would stand a higher temperature.

The bath is 42 in. deep and 20 in. in diameter and takes about 60 gallons of oil. It is very carefully lagged with about six inches of mineral wool; the stirrer puts in about half a horsepower; the main heating coil puts in at the highest temperature another half-horsepower, and the thermostat control coil will operate on about 200 watts. The oil is circulated so rapidly that if the current is thrown on to the heating coil, a mercury resistance thermometer will indicate that fact within five seconds.

Another thing that was done to the plug case was to take out the old solid asbestos-wool lagging and put in combed asbestos wool, which entirely fills the space around the plug and through which the steam flows in practically streamline condition; this has practically halved the heat leak.

It is always interesting to try to compare work on one fluid with any work that there may be on other fluids, because in this case there are no Joule-Thomson observations on steam which pretend to be as precise as the measurements which have been made in the present research, but there are two good sets of values on other fluids. In order to compare various fluids, use has been made of the law of corresponding states. If, instead of plotting pressure in pounds per square inch and temperature in degrees centigrade, the critical pressure for each substance is used as its unit of pressure, its critical temperature as the unit of temperature, and its volume is expressed in terms of its critical volume, then there will be obtained what are known as the reduced temperature and reduced pressure of the substance. The law of corresponding states says that the properties of all fluids may be the same in reduced units, and, like most laws, it is useful chiefly for its deviations; that is, we study the deviations from the laws. But in particular the law of corresponding states has been found fairly useful for specific volumes; that is, by making small corrections, various investigators have succeeded in making it fit for specific volumes; few, however, have attempted to make it fit calorimetric quantities.

It is very easy or relatively so, to make experimental measurements, at around room temperature. The values available on carbon dioxide range from about −30 deg. fahr. up to +100 deg. fahr. At the same time they extend considerably higher in reduced temperature than our steam values up at 650 deg. fahr. So that if a basis of comparison can be found between the properties of carbon dioxide and the properties of steam in this respect, we can extend the range of steam observations; we can make a fairly good estimate of the Joule-Thomson effect in steam at very high temperatures from the atmospheric-temperature observations on carbon dioxide.

Progress Report on the Joule-Thomson Effect

By HARVEY M. DAVIS,[1] CAMBRIDGE, MASS.

IT IS with some hesitation that the following addition to Dr. Kleinschmidt's progress report is presented at this time. A revision of any or all of the existing steam tables is certainly still premature for many reasons. The Harvard Joule-Thomson data are as yet incomplete in range, and some of our points need rechecking. The valuable data which Dr. Keyes will soon be getting will throw much new light on the situation. Dr. Osborne's work on the vapor dome is urgently needed, not only for its own sake but also as the foundation on which we all must depend for our constants of integration in determining total heats and entropies in the superheated region, and Professor Callendar in London is now measuring both specific heats and Joule-Thomson coefficients. No time should therefore be wasted on elaborate computations when there is at hand only a fifth or a sixth of the new experimental data that will soon be available.

Nevertheless every experimenter has a lively curiosity as to the ultimate trend of his work. Furthermore, even a crude rehearsal of one of the methods by which a steam table can be computed may be of considerable value just at this time for three reasons. In the first place, it serves to bring out clearly the gaps which should be filled in by further experiments. It has, indeed, been an unusual pleasure to deal with a mass of data that is still in the making, rather than to have to make what one can out of a finished job.

In the second place, actual experience with a proposed method of dealing with these data brings out both its advantages and its weaknesses. If the speaker were to repeat immediately the work which he is about to describe, he could get much more reliable results even from the same data, because he now knows where and how to take especial pains.

And in the third place, the especial strength of The American Society of Mechanical Engineers' steam-research program is the emphasis laid on coöperation between the various experimenters. This means that each set of data should be digested and checked against the rest; and there should be full discussion and frank criticism before publication, rather than afterward, as is usually the case with research work. It is therefore desirable that each investigator should submit to the group as often and as fully as circumstances may permit, progress reports, not only on experimental details but also on the deductions that may be drawn from the data as they come in, so that these deductions may be the more readily checked against other work.

We start from a diagram prepared by Dr. Kleinschmidt which shows μ as a function of pressure at various temperatures. The isotherms in his diagram are parabolas of the form:

$$\mu = \mu_0 + Ap - Bp^2$$

and the constants μ_0, A, and B are so chosen as to plot smoothly against temperature. The constant μ_0 is the value which μ would approach if the volume were increased and the pressure decreased indefinitely at any given constant temperature; it will be convenient to speak of it as the value of μ "at zero pressure." Our values of μ_0 at various temperatures are still somewhat uncertain; those shown on Dr. Kleinschmidt's diagram are smoothed by means of the purely empirical equation:

$$\mu_0 = 0.052\, e^{\frac{1800}{T}} - 0.025$$

where T is the absolute centigrade temperature and μ_0 is in centigrade degrees per kg. per sq. cm. This formula gives positive values for μ_0 at all temperatures, whereas μ_0 almost certainly becomes negative at very high temperatures. But this theoretical defect is probably not important in the present connection. With the help of these equations, μ can be plotted against temperature at constant pressure, for $p = 0, 2, 4$, etc., to 40 kg. per sq. cm.

The second step is to obtain by integration a family of constant total-heat curves. This is easily done, apparently with satisfactory precision, by a simple arithmetical step-by-step process.

In a more careful discussion of our final data the results obtained in this way would be checked and, if necessary, slightly corrected by means of an integrating machine. Eleven of the 21 curves obtained in this way are shown in Fig. 10, which is a t-p plot bounded below by the saturation curve.

The constant total-heat curves are throttling curves of the sort made familiar by the work of Grindley, Griessman, and Peake. The precision attainable by the Harvard method of measuring μ itself by means of experiments with small pressure drops, rather than determining the throttling curve as a whole by means of experiments with large pressure drops, will be evident from the fact

[1] Professor of Mechanical Engineering, Harvard University. Mem. A.S.M.E.

that two more decimal places were carried in the computed temperatures than could possibly be read from even so large a diagram as the original from which Fig. 10 is reproduced (28 in. by 34 in.) As later appeared, the second of these decimal places was probably of little value in this particular case because of inaccuracies in the μ plot used, but this need not be the case again.

The curves shown in Fig. 10 are spaced evenly at 20-deg. intervals along the $p = 0$ axis (10-deg. intervals in the original plotting). Everywhere else in the figure the vertical intervals between them are less than 20 deg., and the closeness of their approach is a measure of the variation of C_p over the plane. Thus, for example, suppose that the value of the total heat H all along the nth curve is H_n, and that the value of H along the next higher curve is $H_n + \Delta H$. Then the quantity ΔH of heat will just suffice to carry

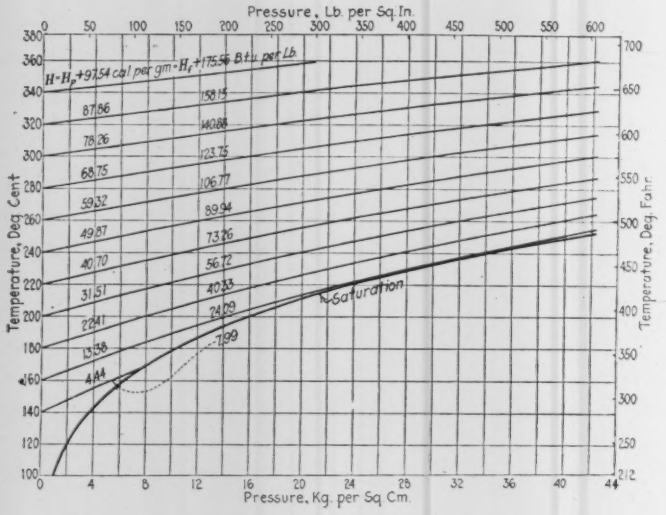

Pressure, Lb. per Sq. In.
Temperature, Deg. Cent.
Temperature, Deg. Fahr.
Pressure, Kg. per Sq. Cm.
H-Hp+9.754 cal per gm-Hf+175.5 B.t.u. per Lb
Saturation

FIG. 10 STEAM CHART. TEMPERATURE VS. PRESSURE AT VARIOUS CONSTANT TOTAL HEATS

(To make total heats comparable with values in the Marks and Davis Steam Tables, use H_c = 655.60 cal. per gram or H_f = 1180.08 B.t.u. per lb.)

a pound of steam from any point on the lower curve to a point on the upper curve vertically above the first point. Along the portion of the zero-pressure axis lying between these two curves, the corresponding temperature rise is 20 deg. If at some other pressure the vertical interval is only 10 deg., then, at this particular pressure, C_p over the particular temperature interval in question is just twice as great as the C_p at zero pressure over the temperature range there intercepted. If each of these C_p's is referred to its own average temperature, we can say that the C_p at the high pressure and a particular temperature is twice the C_{p0} at zero pressure and a different but definite temperature determined by a total-heat curve drawn through the initial point. We have thus a means of expressing each C_p at any pressure and temperature as a C_{p0} at zero pressure and a proper (although different) temperature, multiplied by a ratio factor that can be determined by our family of throttling curves.

Therefore, a subtraction and a division applied to the results of the arithmetical process mentioned above suffice to give the coördinates of any one of the intersections of the two families of curves on Fig. 11. On this diagram abscissas are temperatures and ordinates are the ratio factors just defined. The curves sloping downward to the right are constant-pressure curves. They would constitute a specific-heat diagram of the familiar sort if C_{p0} were the same at all temperatures and if an appropriate vertical scale were attached. Since C_{p0} is not a constant, this diagram must be sheared in a special way to become a specific-heat diagram of the usual sort.

The curves sloping downward to the left are what might be called the units of this shearing proeess. Each is a line of constant total heat. The C_{p0} at the bottom of any of these lines is the one to be used with ratio factors along that particular line to give the corresponding C_p's. With the help of such a diagram C_p's can be computed all over the plane (within the range covered) if C_p is known as a function of temperature at zero pressure (C_{p0}), or at atmospheric pressure, or at any other constant pressure, or indeed if *any one* C_p on each total-heat curve is known, this one C_p playing a part like that of a constant of integration.

This is as far as we can go in this particular direction on the basis of Joule-Thomson data alone. Another line of attack, which leads to information about specific volumes, will be reserved for discussion at some other and more appropriate time.

We may now approach a question that was left unsettled when the steam-research program was initiated. There are available 231 direct measurements of C_p at various pressures up to 30 kg. per sq. cm. (427 lb per sq. in. abs.) and at various temperatures up to 573 deg. cent. (1063 deg. fahr.) in four papers by Knoblauch and certain co-workers. If this work, when checked against the results of the A.S.M.E. program, shows substantial mutual consistency, it will scarcely be worth while to spend the money necessary to make any considerable new series of specific-heat measurements unless higher precision seems desirable. If inconsistency appears, the situation is much less satisfactory.

Of these 231 C_p's of Knoblauch, 178 fall within the temperature range so far explored at Harvard, and our ratio-factor diagram gives us a means of testing the consistency of these two pieces of work. From each of Knoblauch's 178 C_p's, one can compute a corresponding C_{p0} and its appropriate t_0. When these C_{p0}'s

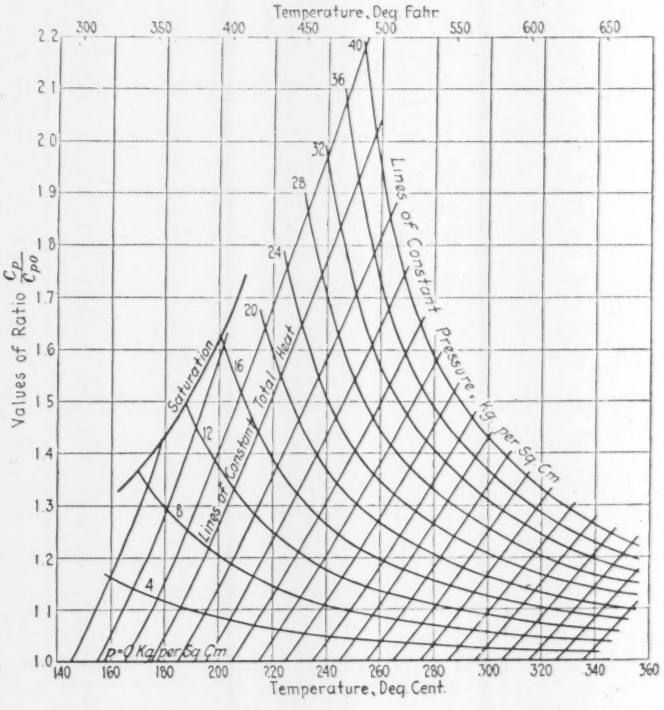

Temperature, Deg. Fahr.
Values of Ratio Cp/Cp0
Temperature, Deg. Cent.
Saturation
Lines of Constant Total Heat
Lines of Constant Pressure, Kg. per Sq. Cm
p=0 Kg per Sq. Cm

FIG. 11 RATIOS OF C_p AT ANY PRESSURE AND TEMPERATURE TO C_p AT ZERO PRESSURE (ABS.) AND AT THE SAME TOTAL HEAT

(NOTE—Lines running N. E. and S. W. are lines of constant total heat.)

are plotted against their t_0's, one would get, under ideal conditions, a single well-defined curve giving the variation of C_{p0} with temperature. If a band of points results, one must examine it for systematic divergences between its constituent groups of points. If, for instance, all the C_{p0}'s derived from C_p's at very high pressures lies distinctly above or distinctly below those originating in low-pressure experiments, then Knoblauch's work and the Harvard work are inherently inconsistent. If, however, no such systematic divergence appears, then the width of the points is merely an indication of the self-consistency (or precision) of Knoblauch's experimental data. The result of such a test is shown in the upper part of Fig. 12. It is evident that the agreement is on the whole satisfactory, especially if one remembers that the vertical scale of this plot is substantially equivalent to that of our ratio-factor plot. That is, a group of points that would cover a vertical range of some 45 cm. on an ordinary specific-heat plot, are here compressed by means of our ratio factors into a band

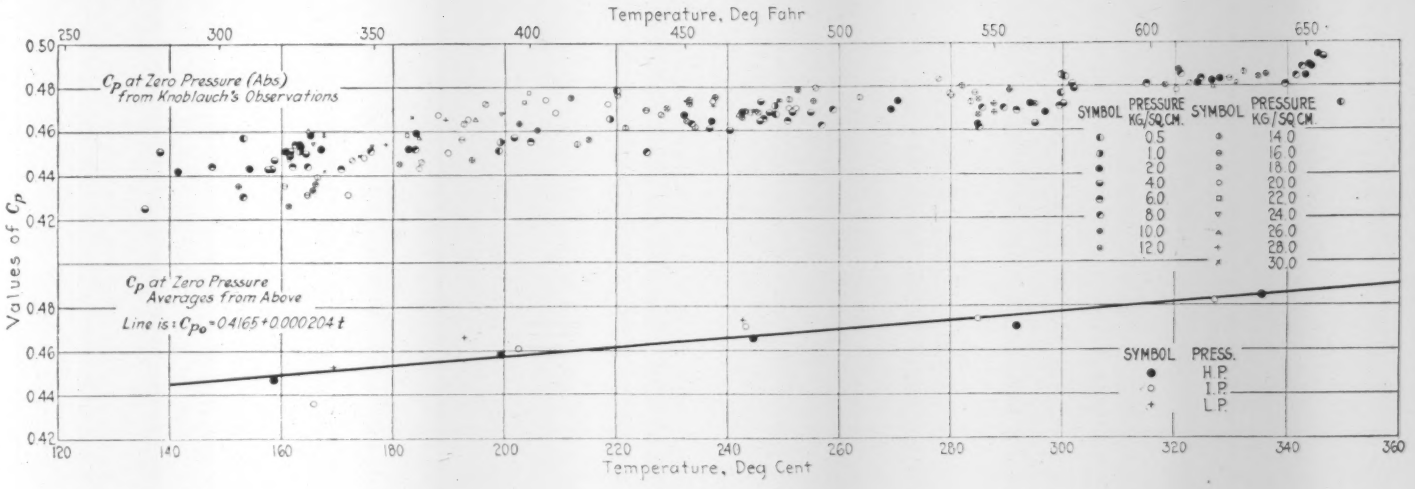


FIG. 12 C_p AT ZERO PRESSURE (ABS.) FROM KNOBLAUCH'S OBSERVATIONS AND LINE PLOTTED FROM AVERAGES THEREOF

2 to 3 cm. wide,[1] although plotted on the same vertical scale. Furthermore, it is possible that this agreement may be somewhat improved, both by such corrections as can later be made in our ratio-factor diagram, and by a more careful consideration of certain doubtful points in the interpretation of Knoblauch's papers. In particular the speaker is not sure whether Knoblauch's C_p's should be referred to mean pressures, as he does, or to low-side pressures, there being appreciable throttling in his apparatus. For the present the speaker has used the data as Knoblauch gives them.

Our C_{p0} plot shows at once that Callendar's assumption that C_{p0} is constant cannot be reconciled with the Munich and Harvard data; the C_{p0} line slopes up in the direction of increasing temperature. The evidence as to its curvature is less convincing. The common assumption has been that it is concave up, but one's general impression of the plot is of a slight downward concavity. To test this, and also to make systematic divergence more evident if it exists, the speaker has grouped the points into five temperature ranges, and within each range he has averaged separately the points originating in low-, in moderate-, and in high-pressure experiments. At the lowest temperatures the high- and the low-pressure means happen to agree very well, while the intermediate mean runs low. At the next higher temperatures it is the high-pressure mean that diverges from the other two. In the other three temperature ranges the agreement is as good as could be expected. Furthermore, at the lowest temperatures all three means are a little lower than one would expect from the rest of the means. The speaker doubts if these small but apparently systematic discrepancies indicate real inconsistency between the two sets of data. He is more inclined to ascribe them to slight systematic errors in the preparation of the ratio-factor chart, some other indications of such errors having come to light since the chart was prepared. It is believed that a more careful repetition of this work would give slightly higher C_{p0} values at the lowest temperatures, yielding a C_{p0} curve with a slight upward concavity as expected. For the present, however, the straight line in the lower part of the C_{p0} plot may be accepted as a sufficiently good first approximation over the particular temperature range in question.

We are now in a position to assign definite H values to the various total-heat curves in Fig. 10 (except of course for a single unknown constant of integration). These values are obtained by integrating the selected C_{p0} line and are entered on Fig. 10, thus making it a rudimentary but effective steam table as far as total heats go.

We can arrange it in a more convenient form for certain purposes, by replotting it on a total-heat temperature plane, as in Fig. 13. The curves in this diagram are constant-pressure lines, and if we mark on each the point corresponding to its saturation temperature, we have at once a graphical determination of the variation of the total heat of dry saturated steam with tempera-

[1] This width is that on the original chart (24 in. wide by $7^1/_{16}$ in. deep) from which Fig. 12 has been reproduced.—EDITOR.

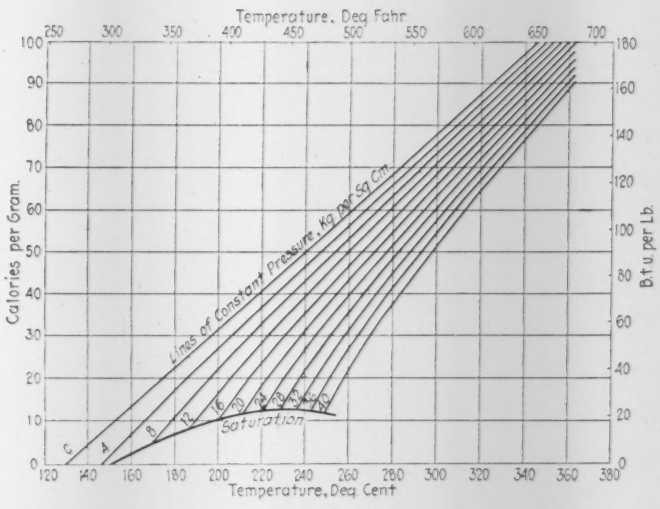


FIG. 13 STEAM CHART. TOTAL HEAT VS. TEMPERATURE AT VARIOUS CONSTANT PRESSURES (PRESSURES IN KG. PER SQ. CM.)

(To make total heats comparable with values in the Marks and Davis Steam Tables, add 655.60 cal. per gram or 1180.08 B.t.u. per lb.)

ture. We thus repeat over a much wider range, and it is believed in a much neater way, the work which, fifteen years ago, first led the speaker into the steam-table field. The highest of the means on which he then depended for the determination of $H_{sat.}$ lay at about 186 deg. cent.; and the highest point at which two observers could be checked against one another lay at about 172 deg. cent. The present determination cannot yet be extrapolated below about 150 deg. cent., although observations of the Joule-Thomson effect at lower temperatures will be undertaken in the near future. There is, therefore, only a short range over which the new determination can be checked against the old. Over this range the $H_{sat.}$ curve rises slightly less rapidly than the old, the divergence being about 0.4 B.t.u. per lb. from 150 deg. cent. to 172 deg. cent., and a little less than 1 B.t.u. per lb. over the whole common range. Furthermore, if the conclusion mentioned above as to the low-temperature end of the C_{p0} curve, which was arrived at on quite independent grounds, proves to be correct, even this small discrepancy will partly or wholly disappear.

This comparison of the old and new determinations of $H_{sat.}$ enables us to fix the last remaining constant of integration, namely, the number that must be added to all the total-heat values on Figs. 10 and 13 to make them comparable with the familiar H values based on water at 32 deg. fahr. It appears that the zero of the present temporary H scale corresponds to H_0 = about 655.60 cal. per gram, or to H_f = about 1180.08 B.t.u. per lb. in the Marks and Davis tables.

The upper limit of the new determination of $H_{sat.}$ is around 250 deg. cent. or 480 deg. fahr., the corresponding saturation

(*Continued on page 108*)

A Calorimetric Method of Surveying the Behavior of Steam

Description of Elements of Method Forming Basis of the Experimental Program on the Properties of Steam upon Which the Bureau of Standards Is at Present Engaged

By N. S. OSBORNE,[1] WASHINGTON, D. C.

THE formulation of steam tables has lately engaged attention and study because of the increasing economic influence of steam-engine design, and extension of the range of temperature and pressure in steam-power practice. We may suppose that from the engineer's standpoint existing practice indicates fairly well the form in which the properties of steam should be tabulated. Recognized virtues in a steam table are adequate range, truthfulness, consistency, and the ability to represent the substance of the table by simple working formulas.

In preparing a steam table two important stages in the work are (*a*) the experimental, by which the behavior of steam is observed and recorded, and (*b*) the formulation, whereby the experimental facts are digested, reduced to order, and expressed in the desired form. There is occasion for judicious choice in both these parts of the work, for of the several possible methods of observing and formulating the properties of steam, none is obviously best. Of course, the procedure in obtaining the physical facts about the fluid's behavior is naturally the first thing to consider in a systematic study of the problem. It is an advantage to anticipate the possibilities and limitations of the experimental part of the work in order the more intelligently to plan the method of formulation. The methods available for the survey of the thermal behavior of steam are of primary and vital interest.

It might be thought that a natural plan of experimentation would be the imitation of the actual processes which take place in a steam power plant, making provision for the accurate observation of all the quantities involved. This would be reasonable except for the fact that we are not concerned with a study of thermodynamic processes, but seek to learn the values of the specific properties of the steam itself. So we may choose any process which exhibits these characteristic properties in any way which seems most expedient in the laboratory. We may simplify the process and isolate it from extraneous disturbing influences so that we may make a certain thing take place in the fluid, accurately observe what happens, and thereby deduce the numerical values of one or more of the properties which define the behavior of steam. Moreover we are not restricted as to the scale upon which we make the experiments. Whether a calorimeter of one quart or of fifty gallons capacity will be most convenient to construct and operate, or capable of the greater accuracy, may be decided by the experimenter on the score of expediency alone.

It is proper to observe that the difference in procedure and design of equipment either to obtain power from coal economically or to obtain knowledge of the properties of steam, is not the result of a point of view peculiar to either problem, but arises from recognition and consideration of the difference in the problems and the availability of resources for the solution of each.

In the past there has been a tendency to favor measurements of the relations between pressure, volume, and temperature in preference to direct calorimetric measurements as a source of *precise* knowledge of the thermal behavior of fluids. This tendency reflects the traditional difficulty of isolating and controlling thermal processes in a fluid so that the quantities of heat exchanged may be accurately measured. For use in formulation, calorimetric data are extremely valuable. It is possible that avoidance of the difficult calorimetric methods may have prevented a due appreciation of the extent to which modern refinements in laboratory appliances and methods have made calorimetry advantageous as a method of making a precise survey of the thermal behavior of a fluid.

[1] Bureau of Standards.

Presented at the Annual Meeting, New York, December 3 to 6, 1923, of THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS. Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce. All papers subject to revision.

The purpose of this communication is to describe the elements of a method of calorimetry of a saturated fluid, which, in principle, is adapted to the determination of a large group of thermal properties of steam *at the saturation limit* which are important in steam-table formulation. The method is the basis of the experimental program on the properties of steam upon which the Bureau of Standards is at present engaged. The analysis of the method is given in detail in a paper now in preparation. The results of this analysis are assumed in the present paper, and it will be the aim here to explain how a series of heat measurements, coördinate with observations of temperature and pressure, suffice to evaluate those properties of saturated steam which usually find place in the working tables.

DESCRIPTION OF PROPOSED EXPERIMENTS

Without stopping to consider any of the many technical problems which the experimenter must first solve before putting the plan into effect, we assume an experimental equipment and procedure as a basis upon which to proceed in developing the underlying principles.

The fluid is to be enclosed in a container or shell made of a suitable, thermally conducting, elastic solid, i.e., a metal. The interior space is provided with a controllable means for introducing measured amounts of heat, in the form of an electric heater, and also with a stirrer or some other means for quickly distributing the heat added through the fluid in the enclosed space and to the solid parts. Outlets are provided for adding or withdrawing fluid. These outlets are provided with valves so that when desired the amount of fluid contents may be kept fixed.

For the purpose of avoiding unmeasured heat leakage the container is located within an envelope. The thermal connection between the two is kept down by employing such refinements as vacuum insulation. The envelope is provided with temperature control so that the temperature difference between it and the container may be observed and kept small. In a complete experiment the slight outstanding thermal leakage may thus be evaluated. A thermometer is provided for indicating the temperature of the container and fluid contents, when in equilibrium. Detachable receivers connected to the outlets are located in an outer bath to hold the part of the fluid transferred to or from the calorimeter and to enable its amount to be determined by weighing.

If the necessary auxiliary devices are provided, the following quantities may be observed:

- *a* Temperature of the container and fluid contents when in thermal equilibrium
- *b* Pressure of the vapor in the calorimeter at any instant
- *c* Initial and final mass of fluid in the calorimeter.
- *d* Entire amount of heat added during any period of time, including that due to thermal leakage and energy dissipated in stirring. This will all be included in the term "heat added."

The system just described may be subjected to the following three distinct processes or types of experiment, each starting and ending with a condition of thermal equilibrium of the calorimeter and contents.

1 In the first type of experiment, by adding heat without changing the amount of contents, the temperature may be raised from an initial to a final equilibrium value. The pressure, specific volumes, and relative proportions of vapor and liquid will of course change, and the volume of the container also to a slight but definite extent. A single experiment of this type will give as a result the thermal capacity of the calorimeter and contents over the temperature interval covered. If two experiments of this kind are made,

each extending over the same interval but with different amounts of water in the calorimeter, the thermal capacity of the calorimeter itself is eliminated by taking the difference, and the result is the thermal capacity of the saturated combination of steam and water. This will be expressed more exactly a little later in an equation which expresses the result of the experiment as a relation between the thermal properties of water and the quantities observed in the experiment.

2 In the second type of experiment a definite portion of the contents of the calorimeter may be withdrawn as *saturated steam* at the temperature of the calorimeter, which is maintained constant during the experiment by adding heat to compensate for the amount absorbed in evaporating the water.

A single experiment of this type gives a result which is, at moderate temperatures, approximately the heat of vaporization, but which differs from this quantity by an increasing amount as the temperature is raised toward the critical point. The difference as a correction term could be calculated from data on pressure and specific volume, but is more directly obtained by an experiment of another type.

3 The third type of experiment is similar to the second in all respects except that the portion withdrawn is in the state of saturated liquid water instead of vapor. The result of this experiment cannot be so readily stated in words as those of the two preceding, but it is a quantity which complements those results in such a manner as to permit the evaluation of certain important thermal properties of water and steam at the saturation limit.

The three types of experiments would of course be carried out in series of single experiments extending over the range of state for which the facts are sought. It is proposed to make all the experiments in the same apparatus. The principle of measuring the heat added electrically is of course the backbone of the method, for it not only furnishes an elegant opportunity for precise measurement, but also gives the result in terms of units best known in absolute value.

It may be pointed out that our ideal calorimeter embodies the principle of conservation of energy. Explicitly, the experimental equipment and procedure which have just been prescribed are merely the expression of the bare essentials whereby three simple thermal processes may be caused to take place in a space so guarded from external influence and provided with measuring devices that we may accurately account for heat added, amount and state of the water, and work done.

Expression of the Results of Experiments

We have now considered what must be provided as equipment and operation. It will be of interest to examine what we may expect to get out as returns. In order to express the results in simple but precise manner it will be necessary to employ symbolic language.

By application of the first law of thermodynamics and suitable reduction it may be shown that for a pair of experiments of the first type, i.e., where the amount of water in the calorimeter is kept constant in each experiment, the immediate result is expressed by the equation

$$\left[H - \frac{u}{u' - u} L\right]_1^2 = \frac{[Q_b]_1^2 - [Q_a]_1^2}{M_b - M_a}$$

where M_a and M_b denote the masses of contents in two experiments going from state (1) to state (2), and $[Q_a]_1^2$ and $[Q_b]_1^2$ denote respectively the measured heat added in each. L denotes latent heat of vaporization, and u and u' specific volumes of liquid and vapor, respectively; H is the "heat content" of unit mass of saturated liquid, sometimes called "total heat," and defined as the sum of the internal energy and the pressure-volume product per unit mass.

The quantity $\left[H - \frac{u}{u' - u} L\right]$ is characteristic of this type of experiment and may for convenience be denoted by the symbol α.

The result of an experiment of the second type is expressed by the equation

$$\frac{u'}{u' - u} L = \frac{1}{M_2 - M_1}\left[-Q'\right]_1^2$$

in which Q' denotes the heat added in this type of experiment where saturated water vapor is withdrawn to the amount of $M_2 - M_1$. The symbol γ may be taken for the quantity $\frac{u'}{u' - u} L$ which is characteristic of this type of experiment. The quantity of heat is of course the quantity corrected for all variations of the experiment from the ideal one in which the temperature would be kept constant throughout.

The result of the third type of experiment is expressed by the equation

$$\frac{u}{u' - u} L = \frac{1}{M_2 - M_1}\left[-Q\right]_1^2$$

in which Q denotes the corrected amount of heat added in this type of experiment. The symbol β may be used to denote the quantity $\frac{u}{u' - u} L$ which is characteristic of this type.

We thus have three quantities each characteristic of a particular type of experiment, completely determined as functions of temperature or pressure. These are, in terms of familiar properties of the saturated fluid,

$$\alpha = H - \frac{u}{u' - u} L$$

$$\beta = \frac{u}{u' - u} L$$

$$\gamma = \frac{u'}{u' - u} L$$

and we may proceed to derive the expressions which serve to evaluate the thermal properties which are the ultimate objects of the experiments.

We have by direct algebraic combination of the above equations

$$H = \alpha + \beta$$

$$L = \gamma - \beta$$

$$\frac{u'}{u} = \frac{\gamma}{\beta}$$

and if H' denotes the heat content of saturated vapor, then, since $H' = H + L$,

$$H' = \alpha + \gamma$$

By making use of thermodynamic relations which involve the second law of thermodynamics an additional group of properties may be derived from the same group of experimental heat measurements. This group includes the entropies ϕ and ϕ' of the saturated liquid and the saturated vapor, the entropy of vaporization L/θ, and the specific heats σ and σ' of the saturated liquid and vapor, respectively. The expressions for these derivations are as follows:

$$\left[\phi\right]_1^2 = \int_1^2 \frac{\delta\alpha}{\theta} + \left[\frac{\beta}{\theta}\right]_1^2$$

$$\frac{L}{\theta} = \frac{\gamma - \beta}{\theta}$$

$$\left[\phi'\right]_1^2 = \int_1^2 \frac{\delta\alpha}{\theta} + \left[\frac{\gamma}{\theta}\right]_1^2$$

$$\sigma = \frac{\delta\alpha}{\delta\theta} + \theta \frac{\delta}{\delta\theta}\left(\frac{\beta}{\theta}\right)$$

$$\sigma' = \frac{\delta\alpha}{\delta\theta} + \theta \frac{\delta}{\delta\theta}\left(\frac{\gamma}{\theta}\right)$$

If we have observed the vapor pressure in addition to the other quantities already specified, and as a result have the vapor pressure as a function of temperature, we may use it to evaluate the two specific volumes from the calorimetrically measured quantities α and β. Thus

$$u = \frac{\beta}{\theta \frac{dp}{d\theta}}; \qquad u' = \frac{\gamma}{\theta \frac{dp}{d\theta}}$$

The accuracy with which the specific volumes can be determined by this means is of course limited by the accuracy with which the several factors can be determined by the experiments, and it is evident that in the case of a liquid at moderate temperature and pressure, such for instance as water between the ice and steam points, other more familiar methods would be capable of far greater accuracy. But aside from that limitation the method has certain advantages which adapt it to the general survey of thermodynamic behavior of fluids for engineering purposes. The chief advantage lies in the fact that the volumetric calibration of a container is obviated, an experimental operation attended with especial difficulty at extraordinary temperatures and pressures. In determining the *vapor volume* the proposed method has the advantage that the experiments may be carried out under *actual saturation conditions*, whereas direct determinations of saturated-vapor volumes are usually made by extrapolating to the saturation limit from observations made at a small degree of superheat. Furthermore the proposed method contemplates a thorough circulation of the fluid and thus avoids much of the difficulty which attends direct observation of vapor pressure or specific volume because of the retardation of equilibrium by traces of impurity in the fluid when no means are provided for stirring.

It may be noted that when we determine specific volumes in the manner indicated we are, in reality, reversing the procedure frequently used to evaluate the heat of vaporization of a fluid by use of Clapeyron's equation when the temperature, pressure, and specific volumes have been observed. By reviewing the reduction formulas just preceding, it may now be seen that observations made in a single instrumental set-up suffice to complete the evaluation of an essential group of thermal properties of a saturated fluid, in a manner which not only is consistent thermodynamically, but in which an accuracy might be anticipated which would be consistent with the use of the results in engineering calculations.

If it should be found expedient to determine the capacity of the calorimeter as a function of temperature and pressure, then it would be possible to use this capacity as a measure for determining the specific volume of the liquid and thus furnish a valuable check on the accuracy of the results.

Remarks on the Application to Steam-Table Formulation

It remains to point out in conclusion that the surprisingly simple system of obtaining data as to the behavior of water and steam at the saturation limit which is the direct outcome of rigorous analysis, and which is comparatively easy to accomplish on paper, is of use to us only to the extent that the assumed experimental operations may be successfully provided for and carried out in the laboratory. Consideration of this phase of the work will be the subject of another communication. It is not really as though the method proposed were completely novel and untried, for in its fundamental essentials the method follows previous calorimetric work on liquid ammonia, and the experience in this previous successful investigation has guided the development of the present project. An advance has been made, however, in that further study has placed the method of calorimetry of a saturated fluid on a more systematic basis whereby the actual experimental program is simplified, and it becomes evident how instrumental refinements will promote simplicity of operation and reliability of results. It may be said here that so far as the study has progressed from the standpoint of laboratory technique, no insuperable obstacles have appeared; although the undertaking to effect by the proposed means an extensive survey of the thermal behavior of saturated steam is more formidable than might at first be apparent to those unaccustomed to precise control and measurement of thermal processes in fluids outside the ordinary range of temperatures and pressures.

As an offset to this adverse feature of experimental difficulty there is the advantage to be hoped for of making available for formulation the thermal properties of steam in the extremely imoprtant saturation region. The possibility of determining this entire group of data as a thermodynamically consistent result of direct calorimetric measurements of high precision starting from a datum in the liquid state and extending over the entire range of temperature and pressure, by a method of demonstrated practicability, will be recognized as an asset in considering the systematic formulation of a complete steam table.

Discussion[1]

THE scalar layouts in Figs. 1 and 2 visualize quantities and illustrate the algebraic relations in the fourth column of Mr. Osborne's paper. The outstanding quantity is β, an apparent adjustment on heat of liquid H and latent heat L. What is β as a physical quantity? Is it a property of steam or a property of the experimental operation?

Use v for the vaporization volume-change $(u' - u)$; then $L/v = K$ is the latent heat in B.t.u. per cu. ft., the general terms of measurement. Now it appears that $\beta = uK$ is the heat required to evaporate a quantity of steam equal in volume to the saturated liquid.

The author's second and third types of experiments are constant-pressure and isothermal operations, conditioned by a constant contained volume in the calorimeter. In the third, liquid mass M is withdrawn and heat $M\beta$ produces are placing volume of vapor from the liquid remaining in the calorimeter. In the second experiment mass M is withdrawn as it vaporizes: heat ML is

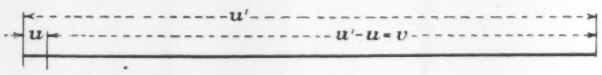


FIG. 1 VOLUMES

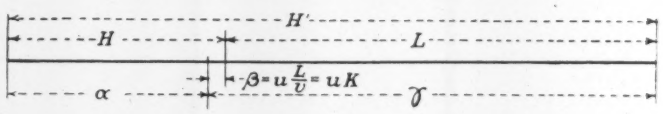


FIG. 2 HEAT QUANTITIES

required for the steam thus formed and $M\beta$ for the volume of vapor that replaces liquid M.

The first experiment is a constant-volume heating, involving mostly liquid but also a small amount of vapor. In a single experiment of this type the added heat changes internal energy, which for the liquid is $H - Apu$ and for vaporization is $L - Apv$. Using H and L for these energies, the total value per pound in the calorimeter is $H + xL$, with vapor factor x a small fraction. The calorimeter volume being V, this x is $(V - Mu)/Mv$; then substituting and reducing, we come to

$$\left[Q_b\right]_1^2 - \left[Q_a\right]_1^2 = (M_b - M_a)\,[(H_2 - H_1) - (u_2K_2 - u_1K_1)]$$

$$= M\left[H\right]_1^2 - M\left[\beta\right]_1^2$$

the terms that involve V canceling when the difference is taken.

Again, though by no means so simply, heat β takes care of the change in vapor quantity, which increases with rise of pressure. It is negative because more vapor is associated with smaller contained mass M_a.

In order to give an idea of the absolute and relative magnitudes of correction term β, the following values have been taken or computed from the writer's Steam Formulas paper of 1920, Table 4.[2]

t	250	300	350	400	450	500	550	600
p	29.83	67.02	134.57	246.99	421.71	679.1	1142.8	1540.7
L	946.52	911.38	871.94	827.06	775.50	716.14	646.73	559.09
L/β	812.7	370.1	185.0	98.94	55.48	32.10	18.89	10.70
β	1.17	2.46	4.71	8.36	13.98	22.31	34.25	52.24

The relative quantities involved in an experiment of the first type mentioned by the author are illustrated by the following results from an example worked by the same steam formulation, for the water masses $M_a = 1$ lb. and $M_b = 2$ lb., with a calorimeter volume $V = 0.05$ cu. ft., taken to be invariable:

1	Steam temperature t		300	400	500
Case (b), $M = 2$ lb.:		liquid	538.56	746.56	961.50
2	Internal energy	vapor	1.94	5.07	8.65
		total	540.50	751.63	970.15
3	Heat added		211.13	218.52	
Case (a), $M = 1$ lb.:		liquid	269.28	373.28	480.75
4	Internal energy	vapor	4.19	12.56	28.40
		total	273.47	385.84	509.15
5	Heat added		112.37	123.31	
6	Difference, for $M_b - M_a = 1$ lb.		98.76	95.21	
7	Heat of liquid, H		269.50	374.13	483.33
8	Corrective term, β		2.46	8.36	22.31
9	Quantity measured in Expt. [1], α		267.04	365.77	461.02
10	Difference		98.73	95.25	

(*Continued on page 108*)

[1] By R. C. H. Heck, Professor M. E., Rutgers College. Mem. A.S.M.E.

[2] Trans. A.S.M.E., vol. 42, p. 738.

SURVEY OF ENGINEERING PROGRESS

A Review of Attainment in Mechanical Engineering and Related Fields

The Mercury-Vapor Boiler and Turbine

THE installation at Hartford of a mercury boiler and turbine marks the first step in a development of several years' duration to utilize commercially two fluids in a heat engine and thereby to increase the thermal economy. The Hartford Electric Light Company, a pioneer in adopting new power-plant equipment, was the first to employ a steam turbine in a central station in this country, and it is interesting to note that since the new prime mover has been installed at the Dutch Point Plant, much less trouble has been encountered in its operation than was experienced with the first steam turbine installed in the same plant in 1899. It must be realized, however, that the present mercury boiler is but a first step. Time alone determines the true value of an invention, and that must undoubtedly be the case with the mercury-vapor power plant. Its principle is simple, but its successful utilization has already demanded the solution of scientific problems of a high order. Many technical and commercial obstacles must still be overcome. As the success of the steam engine depended upon the invention of a boring machine to produce accurate cylinders and as the automobile and the airplane demanded an advance in the internal-combustion engine, so the demand for greater economy in power generation has compelled the study of the mercury turbine, and with its successful commercial development will come the solution of many related problems.

Great credit is due to W. L. R. Emmet, Mem. A.S.M.E., who has spent many years on this project, for his courage and patience. The encouragement of the engineering profession goes with him as he carries the pioneer work forward.

The prospect of securing a kilowatt-hour from the electric generator at the expense of 10,000 B.t.u. in the furnace is very alluring to the power-plant designer and operator. Hitherto, 13,700 B.t.u. per kw-hr. has been the result attained in large modern steam-turbine plants and the equivalent of 14,030 B.t.u. per kw-hr. has been achieved in a large reciprocating pumping engine. The Hartford unit, which has not as yet borne its full load, has approximated the 10,000-B.t.u. result, and engineers are now waiting for information as to the construction, maintenance, and operation costs of units for central-station service.

The Mercury-Vapor Power Plant

The basic idea of this binary-vapor power plant is simple. Referring to Fig. 1, mercury is vaporized in a boiler *A* which it leaves at a temperature of, say, 812 deg. fahr., and a pressure of 45 lb. The vapor is then expanded in a turbine *C*, to a vacuum of 29 in. and then passes to a condenser *D* where it is liquefied with water as the cooling fluid. As mercury condenses at 414 deg. fahr., the condensing water is converted into steam, so that in the steam space above the condenser there is a pressure of 200 lb. and a temperature of 388 deg. fahr. From the condenser the liquid mercury returns to the boiler through the pipe *E*, while the steam from the steam space of the condenser may either go direct or through a superheater to a steam turbine.

This simple basic idea can, of course, be elaborated by the addition of economizers, feedwater heaters, and superheaters. At the Hartford installation the boiler is oil fired and the flue gases after being used in the mercury boiler are drawn by an induced-draft fan through a mercury heater, a steam superheater, and a feedwater heater on their way to the stack.

The mercury is vaporized in a vertical cylindrical boiler of the fire-tube type with a single tube sheet, allowing one end of the tube to be free for expansion. The boiler holds about 30,000 lb. of mercury and is designed to evaporate 230,000 lb. of mercury per hour. When developing 1900 kw. the unit will also deliver approximately 28,000 lb. of steam per hour at 200 lb. pressure and 100 deg. superheat to the steam mains of the power station. The present type of boiler cannot be inspected or cleaned and another boiler of the mercury-tube type is being designed.

The first description of the mercury-vapor boiler appeared in the January, 1914, issue of the *General Electric Review* in an article by Mr. Emmet entitled Power from Mercury Vapor, in which he explained that the broad principle involved in this process was suggested to him by Mr. Charles S. Bradley, who proposed and patented a process using certain substances, other than water, of high boiling point and relatively high vapor density. Consideration of the possibilities suggested by Mr. Bradley led Mr. Emmet to study the characteristics of mercury, and after a period of experimenting the plans of procedure were evolved. At the time of writing the article in question apparatus for about 100 hp. was nearly completed. The Hartford apparatus is the fifteenth of a series designed to reduce the amount of mercury used, to eliminate expansion strains, to permit free return of the mercury to the boiler, to obviate overheating, and to provide air- and mercury-tight joints.

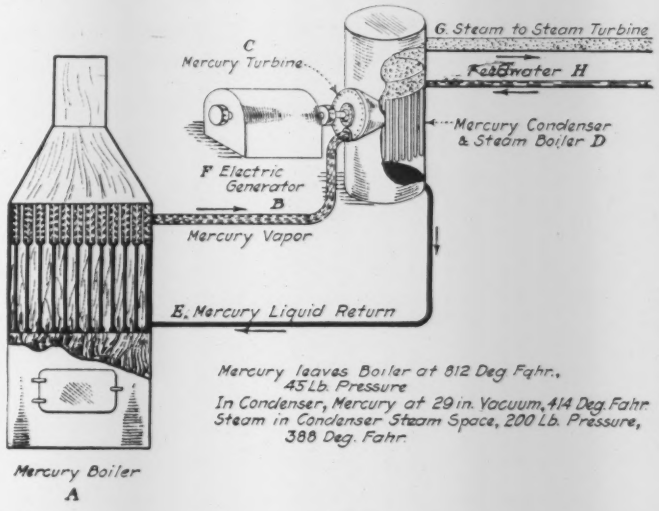

G. Steam to Steam Turbine
C
Mercury Turbine
Feedwater H
Mercury Condenser & Steam Boiler D
F Electric Generator
B
Mercury Vapor
E. Mercury Liquid Return
Mercury leaves Boiler at 812 Deg. Fahr., 45 Lb. Pressure
In Condenser, Mercury at 29 in. Vacuum, 414 Deg. Fahr
Steam in Condenser Steam Space, 200 Lb. Pressure, 388 Deg. Fahr.
Mercury Boiler
A

FIG. 1 DIAGRAMMATIC SKETCH OF THE MERCURY-VAPOR POWER PLANT

Properties of Mercury Which Make it Advantageous for Use in a Binary-Vapor System

In the article above referred to Mr. Emmet also enumerated the advantageous properties of mercury as follows:

Boiling point of mercury at atmospheric pressure, 677 deg. fahr. (358 deg. cent.).

Boiling point of mercury at 28 in. vacuum, 457 deg. fahr. (236 deg. cent.).

Vapor density is in the ratio of atomic weight and absolute temperature; as compared with water it is therefore 6.56 times as great at the boiling point and 6.8 times as great at 28 in. vacuum.

Specific heat of mercury liquid, 0.0373.

Specific heat of mercury gas (constant pressure), 0.0248.

(According to Kurbatoff; *Z. Phys. Chem.*, 43, 104, 1903.)

Latent Heat of Vaporization:

At 25 lb. abs. $r = 117$ B.t.u.

At 15 lb. abs. $r = 118$ B.t.u.

At 28 in. vacuum $r = 121$ B.t.u.

At 29 in. vacuum $r = 121.5$ B.t.u.

(Calculated from formulas by Kurbatoff.)

The boiling point of mercury at various pressures is shown by Fig. 2, and curves are also given in the article showing the energy theoretically available from mercury vapor within various pressure ranges. These curves are calculated from Rankine's formula:

$$E = 778\left[Q_1 - Q_2\left(1 + \log\frac{Q_1}{Q_2}\right) + \frac{x_1 r_1}{Q_1}(Q_1 - Q_2)\right]$$

where E = energy in ft-lb.
Q_1, Q_2 = heat of liquid
X = dryness factor
r = latent heat.

Mercury has certain advantages as a thermodynamic fluid for power purposes, of which the following may be mentioned. Its boiling points at desired pressures are convenient. Its vapor density is so high that it gives a low spouting velocity and consequently a very simple type of turbine can be used; its volume at convenient condensing temperatures is such that it can be used for turbines without excessive exhaust passages. Thus the difficulty which today faces every steam-turbine designer employing high condenser vacuums, namely, efficient discharge of steam from the last stage, does not exist with mercury vapor.

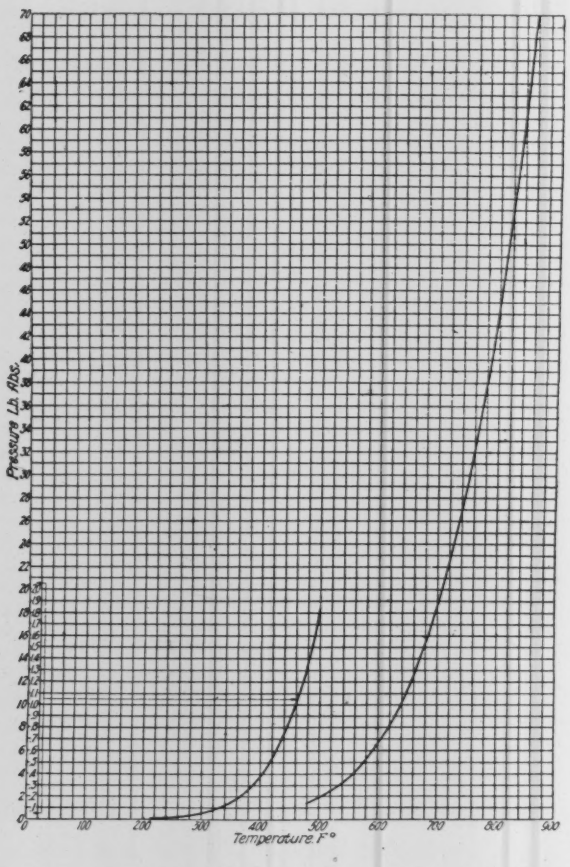


FIG. 2 CURVE SHOWING BOILING POINT OF MERCURY AT VARIOUS PRESSURES

In his paper on Margins of Possible Improvement in the Central Station Steam Plant, presented at the recent A.S.M.E. Annual Meeting, Ernest L. Robinson pointed out as the great advantage of the mercury turbine its utilization of a substance whose vapor pressure will not be excessive at the temperature to which the materials of construction may be submitted. Mr. Robinson also stated the theoretical increase of economy by use of the mercury turbine to be 28.7 per cent over good modern turbine practice with steam at 350 lb. per sq. in. pressure and 700 deg. temperature, and utilizing the extraction cycle to the limit.

DIFFICULTIES WITH THE USE OF MERCURY

In the construction and operation of the mercury unit a property of the mercury was encountered that presented a troublesome problem. Mercury is a pervasive liquid that will with an almost human ingenuity search out every weak place in a structure and make its way through it, and the least porosity in a casting or the smallest crack in a welded joint, which would be perfectly harmless in the case of water or steam at the same pressure, will be utilized as a means of escape. Leakage of mercury is especially undesirable, first, because of the general impression that mercury vapors are extremely poisonous, an impression the correctness of which is by no means certain; and secondly, on account of the high price of mercury. This means that every casting and every welded joint that comes in contact with the mercury must be 100 per cent leakproof, and that only high-grade materials and workmanship can be used. But this is expensive and only the future will show whether the price in terms of first cost, maintenance cost, and obsolescence and depreciation charges can be maintained within the limits which will permit competition with the standard types of prime movers for central stations. In this connection it should be noted that the Hartford unit is an example of unusual excellence in welding construction.

REGARDING THE MERCURY SUPPLY AVAILABLE

A second obstacle to the general adoption of the mercury boiler is the apparent shortage of mercury ores. According to a communication from the U. S. Bureau of Mines, mercury is neither abundant nor widespread in its occurrence. The large producers of mercury are, in the order of normal importance, Spain, Italy, Austria, and the United States, the largest of them all being Spain. The mercury market in Spain is absolutely controlled by the British. Italian production is also largely controlled by English interests, and while the control of the Austrian production is less certain, it is apparently drifting in the same direction. When this is completed English interests will control over three-quarters of the world's mercury.

The output in the United States before the war was normally slightly in excess of domestic demand, but due to the exhaustion of the richer and more easily worked deposits, production is declining and it is expected that the future needs of this country will have to be met by importations from Europe. The visible resources of ore at Almaden, Spain, are estimated at 40,000 metric tons, and those in Austria-Hungary at about one-half that amount.

In 1921 the world's production was 71,339 flasks (one flask = 75 lb.), or 2432 metric tons. The average cost of producing a flask of quicksilver in Europe is about $30. To this must be added the present duty of 25 cents per pound, or $18.75, and the ocean freight of $2 per flask, making a total of $50.75 as the minimum cost to the importer at the dock, which leaves no profit to the producer.

With these data at hand the following figures appearing in an editorial in the *Engineering and Mining Journal-Press* for December 22, 1923, become significant. This journal gives a tentative figure for the total amount of boiler horsepower used in the United States in the mining industries of 2,258,000 hp., which, on the basis of the requirements of the Hartford boiler, would call for nearly 34,000,000 lb. of quicksilver, or more than the total amount produced in the United States in the last twenty-one years. But the total amount of high-pressure steam-boiler capacity used for all purposes in the United States is 18,000,000 hp., and its equipment would require 270,000,000 lb. of mercury.

According to the same journal, the world's production of mercury in 1921 was only 4,451,000 lb. or enough to equip but 148 boilers of the size used at the Hartford plant. The total world's production for the fourteen years from 1908 through 1921 was 110,337,000 lb., or less than half what would be required to change the high-pressure steam boilers of the United States alone to the mercury system.

The question arises whether increased demand would not result in an increased supply. Beyond any doubt such a demand would bring about increased production from present mines and perhaps the exploitation of new mines containing low-grade ore; but this demand would have to be made in terms of higher prices for quicksilver.

Owing to the relatively small quantity of quicksilver produced, its price has been subject to wide fluctuations. For many years before the Great War the price was generally below $40 a flask. If

the demand for quicksilver for boiler purposes grows, it is inevitable that a skyrocketing of prices will take place.

In 1921 the United States, although producing only 6339 flasks (475,425 lb.), still remained the third largest producing country in the world, Italy (including the Idria mine) ranking second, and Spain (with the Almaden mine) first.

Recent Discussion on the Mercury-Vapor System

The following views expressed in a discussion of mercury-vapor prime movers at the Institution of Mechanical Engineers in London last November and published in *The Engineer*,[1] may be of interest.

W. J. Kearton of Liverpool University presented a paper entitled The Possibilities of Mercury as a Working Substance for Binary-Fluid Turbines. This paper was devotep almost wholly to the theoretical side of the subject. The author, grouping all the advantages and disadvantages attending the use of high-pressure steam, said that steam falls short of being an ideal working fluid because at the temperatures we desire to reach to improve the efficiency, the pressures are too high. At the other end its pressure is too low and its specific volume too great at the temperatures of the circulating water, with the result that difficulty arises in providing the necessary area for the flow of fluid in the last stages of a turbine. The mercury curve is not far below the ideal at high temperatures, and even at 400 deg. fahr. its vapor pressure is exceedingly small. At 800 deg. fahr. the vapor pressure of mercury is only just over 45 lb. It would therefore appear that mercury vapor is to be used in a low-pressure, high-temperature turbine combined with the use of steam in a high-pressure, low-temperature turbine.

On the whole Mr. Kearton came to the conclusion that although the efficiency of the mercury-vapor steam turbine is not quite as great as that of the Diesel or Still engine, the plant is mechanically ideal and can be constructed to develop relatively high powers with ease. He doubts if it will ever be adopted for the propulsion of merchant ships, because simplicity and reliability are factors of more importance in such a case than fuel consumption.

In the discussion which followed, I. V. Robinson attempted to estimate what saving per unit generated would accrue if a 10,000-kw. station, such as that at Blackburn, changed from an ordinary steam-turbine plant to the binary principle. Taking the no-load losses into consideration, he estimated that as a result of the improved efficiency the binary-fluid principle would save three-eighths of the steam-turbine fuel. Setting the saving thus represented against an estimated 20 per cent increase in other works' costs, and an increase in capital charges arising from the binary plant being an assumed 25 per cent more expensive than an ordinary steam-turbine equipment, he came to the conclusion that the binary principle would yield a net saving of 0.05d (about 0.1 cent) per kilowatt-hour generated. Should coal rise to twice its present price—an almost unthinkable proposition—the net saving would still only amount to 0.25d per kw-hr. (0.5 cent) even if no allowance were made for the fact that with coal doubled in cost the plant would be more expensive to purchase and install. The proposition could not be regarded as attractive, for no engineer could recommend such a wholesale change for the sake of saving one-twentieth of a penny per unit. In a concrete instance, it might be noted, a London station—that at Stepney—saved a net half-penny (1 cent) per kw-hr. by the installation of a new type of steam turbine.

Further in the discussion Mr. H. W. Patchell emphasized the difficulty of obtaining materials to withstand the high temperatures and the penetrating and amalgamating propensities of mercury. He also pointed out that if mercury vapor contained any trace of mercury moisture, the steel was cut just as if it had been subjected to a sand blast. The need for welding is not a valid objection as welded joints can readily be broken at any time by means of an acetylene jet.

An editorial in the *Practical Engineer*[2] in discussing this subject points out as one of the possible disadvantages the fact that the latent heat of mercury is only about 129 B.t.u. at a temperature of 410 deg. as compared with the latent heat of steam at the same temperature of 830 B.t.u., so that at least $6^1/_2$ lb. of mercury would be needed to provide the latent heat for one pound of steam, and actually over 9 lb. would be needed because, owing to the wetness of the mercury vapor after expansion, the figures have to be divided by 0.7.

The mercury-vapor boiler represents an incursion into an entirely unknown region. It is not unusual for an important development ultimately to take a path entirely different from the one which was mapped out for it by its original creators. Hadfield's manganese steel proved to be valueless as a tool material, but found extensive applications for a number of other useful purposes. The original Mannesmann process was devised to make seamless tubing, but did not prove either economical or satisfactory for this purpose. It has, however, developed into an extremely useful process for piercing billets which are afterward drawn into tubes on the conventional benches. It would not be surprising, therefore, as our knowledge of the binary-vapor power plant develops, if some useful field of application for it outside of the central station were found where its peculiar properties might offer important advantages.

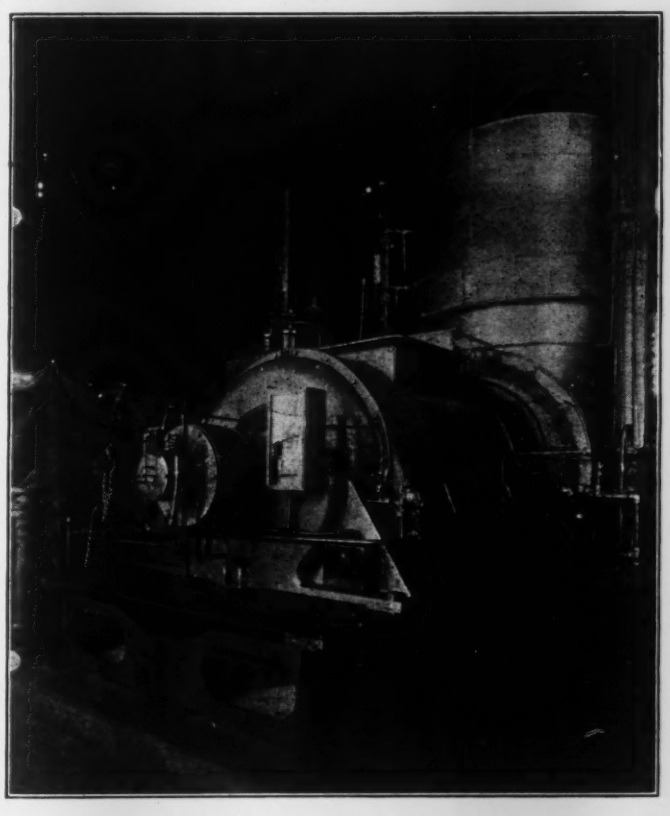


Fig. 3 Mercury Vapor Process Unit at Hartford

Other Developments in the Prime-Mover Field

There are several developments in prime movers which have reached a stage where they may properly be compared with the mercury-vapor boiler. The thermal efficiency of the Diesel engine is well known, but hitherto it has not been seriously considered for central-station work because large units have not been constructed. Lately, however, the German M.A.N. works is said to have completed a unit developing nearly 17,000 hp. in six cylinders. If this development should prove successful it may become an important factor in central-station design. Another type of engine, the Still-Scott, promises higher thermal efficiency than the Diesel. In this engine the cooling water is vaporized to steam partly by the direct action of combustion in the cylinder and partly by heat from the exhaust gases, which later also preheat the feedwater. A small auxiliary oil burner is employed. Recently publisheds test indicated that this device may produce a kilowatt-hour for about 8500 B.t.u.

In the central station today the important requisite for prime movers is reliability, and recently this has been stressed as more desirable than high thermal economy as it tends to a lower overall plant economy. It will be apparent, therefore, that all of these devices must pass through a period of severe trial before competing successfully with the present form of central-station prime mover.

[1] *The Engineer*, vol. 136, no. 3543, Nov. 23, 1923, pp. 563–565, 6 figs.
[2] *Practical Engineer*, vol. 68, no. 1918, Nov. 29, 1923, p. 296.

Short Abstracts of the Month

AERONAUTICS

Rocket and Jet-Propulsion Plane

STATEMENTS have been published in American newspapers, for example, The New York *Times*, Dec. 17, 1923, p. 8, referring to the Melot design of aircraft propulsion. Among other things, these statements contain estimates to the effect that such a plane would have a speed of 600 or more kilometers an hour without difficulty for a beginning. Its ability to climb is estimated to be unlimited.

The Melot system of propulsion for aircraft was described and illustrated in a British paper, from which an abstract was reproduced in MECHANICAL ENGINEERING vol. 42, no. 4, April, 1920, p. 234.

The efficiency of jet propulsion has been investigated by the National Advisory Committee for Aeronautics and the results were published in a report, an abstract of which was reproduced in MECHANICAL ENGINEERING, vol. 45, no. 7, July, 1923, p. 434. According to this report the efficiency of the jet-propulsion system is quite low, at least in all the devices now known.

Stopping Airplane Engines from the Ground

IT is said that a method has been developed in France by which magnetos and ignition coils can be put out of action by the use of Hertzian waves directed from the ground. While no details of the invention are reported, the general method of operation is, of course, fairly obvious. It consists in some way of ionizing by means of directed wireless the air gap between the terminals or field and armature of a magneto or terminals of a coil, which would have the same effect as short-circuiting these parts by a metal conductor.

There would be two ways of meeting this difficulty, namely, one by enclosing the ignition devices into an iron box, and the other by using Diesel-type engines which do not rely on electric ignition for their operation. (A Remarkable Invention and Its Effect. *The Practical Engineer*, vol. 68, no. 1918, Nov. 29, 1923, pp. 295–296, *g*)

ENGINEERING MATERIALS

Tool Production from Hardened Malleable Iron

DISCUSSION on the use of malleable iron for medium-grade tools intermediate between the cheap variety which break easily and the best cast-steel tools selling at a comparatively high price. It is obvious that the best grade of malleable will not make a first-class hatchet, as the head will flatten out and the edge turn over unless those parts have been hardened in some way. It was therefore a question of finding out the feasibility of hardening parts of malleable castings and the nature of the hardened product as well as the process of hardening.

As a preliminary experiment a number of malleable bars were heated to various temperatures and quenched, with the rather unexpected result that the quenched metal was extremely hard, and in many cases had a very fine-grained gray fracture greatly resembling steel.

As a practical test a bar was roughly ground to the shape of a twist drill, then hardened. Successive samples of brass, gray iron, malleable, steel, and hardened white iron were drilled with this tool.

This last was rather a surprise, as in the past the author had been able to drill hard iron only by means of high-speed steel.

In order to determine the actual usefulness of hardened malleable under ordinary shop conditions, a number of hammer heads were cast, hardened, finished, and supplied to carpenters' shops, despatch departments, machine shops, and other departments where hard use was certain.

The results were surprisingly good; three months of hard service failed to develop flaws in any of the hammers, although a number of handles had to be replaced.

It was notable that none of the hammer heads had "mushroomed," as would soft malleable iron, and none had chipped, as would overhard steel.

An effort was then made to find out what would be the best methods to harden malleable and the difficulties encountered. To this end several hundred samples of various shapes were cast and hardened in diverse ways.

For close temperature control a small electric muffle furnace was found ideal, although rather slow in bringing samples to temperature.

For quick work the ordinary blacksmith forge gave excellent results after a little practice. For instance, 100 hammer heads were hardened in 100 minutes, with a loss of only one casting, which was burned.

Warm water was found best for quenching, and quenching cracks were eliminated by dipping the heated hammer head (at about 925 deg. cent. = 1697 deg. fahr.) in the water two or three times, with intervals of about one second between the quenchings.

Hardness readings on 100 samples varied from 40 to 55 scleroscope, which is a satisfactory range for this kind of tool.

It was surprising that the rather wide range in quenching temperatures made little difference in the hardness of tools. In this connection it is pertinent to state that scleroscope hardness readings on some twenty high-grade steel hammers ranged from 40 to 75.

No particular attempt was made to arrive at costs, but it seemed probable that hardened malleable could be produced and finished at less cost than steel of similar physical characteristics. (E. K. Smith in *Canadian Machinery*, vol. 30, no. 22, Nov. 29, 1923, pp. 21 and 38, *epA*)

FOUNDRY

Blast Preheating in Cupolas

DESCRIPTION of a cupola invented by E. Shurmann of Dresden Germany, and built under German plans at the plant of the Griffin Wheel Co., Chicago. The furnace was completed and placed in service early in October and has been in continuous service since that time, alternating with a cupola of the usual type to supply metal for car wheels.

As seen in Fig. 1, the shell of the cupola, the drop bottom, and arrangement of the charging doors are of standard American design.

The wind box extends entirely around the cupola in the usual manner but is divided at opposite points by brick walls which separate it into practically two wind boxes. Each half of the wind box communicates with a sheet-metal preheating chamber lined with firebrick and containing a checkerwork of refractory brick. These chambers are divided and insulated from each other, but are contained within a single sheet-metal structure, communicating at the top through two 24-in. pipes with a common valve chamber.

In operation, the blast is forced through the main supply line from a fan blower, down through the checkerwork chamber, into the tuyeres at one side, across the cupola, out the opposite tuyeres, upward through the neighboring checkerwork, and into the exhaust line. Thus on starting, the exhaust emerging from the cupola passes upward through the chamber adjacent and heats the brickwork within.

At regular intervals, varying from 7 to 10 minutes, the valve is reversed, causing the entering blast to pass downward through the preheated checkerwork and into the tuyeres at a high temperature.

To accelerate the current of exhaust gas passing through the checkerwork, an additional fan has been provided. A two-way valve has been installed on the outlet side of the pipe communicating with the exhaust pipe. When in one position this valve permits from 40 to 50 per cent of the emerging gases to be drawn downward into the fan, and thence out through the valve chamber a second time and into the stack. When reversed, this valve permits all of the products of combustion to pass directly into the stack. At first it was feared the regenerative chamber would injure the fan, and accordingly water-cooled bearings were provided for the fan. However, it has been found that the temperatures of the emerging gases are below 400 deg. fahr., and no trouble is experienced. Air is blown into the cupola preheating chambers at from 6000 to 12,000 cu. ft. per min. and at a pressure of from 12 to 14 oz. The suction exerted on the exhaust side is 3 oz.

Several additional features of the cupola are described in the original article. The cupola is now under experimental service, although on a production basis. Oxidation does not appear to have caused trouble. Some slight loss in the total silicon and manganese has been noted. But inasmuch as the tap hole is left open and the iron flows directly into the forehearth, no difficulty has been encountered due to this. The slag is preheated to flow out with the iron into the forehearth, and it is stated that no slag is found floating on the ladle when the metal is tapped for pouring.

The advantages claimed for the cupola in practice are a saving in coke, a reduction in the sulphur content, and a greater toughness of the iron melted. The company states that the test pieces poured from metal melted in this cupola are much tougher than those from the standard-type cupola. A saving of from 20 to 25 per cent in the amount of coke required to melt a given quantity of iron is reported. The sulphur is said to be about two points lower in the iron when it comes from the cupola than when it was charged. The analysis of the entering charge shows 0.175 per cent sulphur. It is said the metal shows a sulphur content of 0.155 per cent when the metal is taken from the cupola. The melting speed of the Shurmann cupola is about 60 to 70 per cent of another cupola the

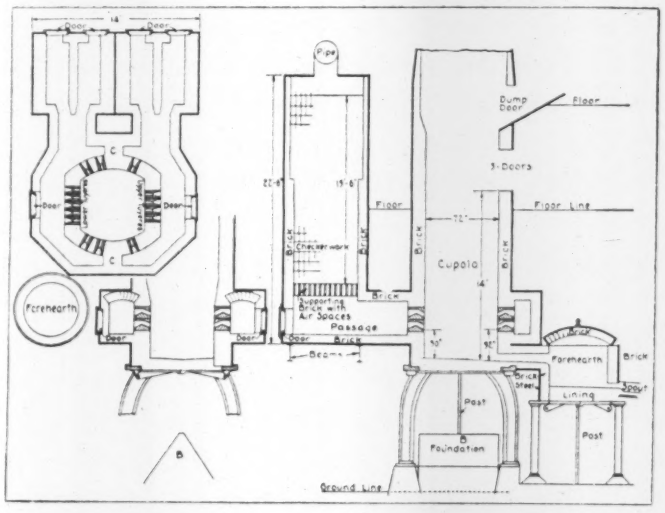


FIG. 1 VERTICAL SECTION THROUGH THE CUPOLA, PREHEATING CHAMBER AND FOREHEARTH, WITH RIGHT-ANGLE VERTICAL SECTION THROUGH THE CUPOLA AT THE LEFT AND HORIZONTAL CROSS-SECTION THROUGH THE TUYERE LEVEL ABOVE

same size in use of the Griffin foundry. A maximum output of 90 tons has been obtained in a single day and the average rate is about 15.5 tons per hour. (Preheat Blast in New Cupola. *The Foundry*, vol. 51, no. 24, Dec. 15, 1923, pp. 994–996, 3 figs., *d*)

Dollin Die-Casting Machine

THE most interesting feature of this device is the valve-control apparatus by which air from the high-pressure system exhausts into a low-pressure system, air pressure being employed to open and close the dies and to force the metal into the die chamber. The air for driving the piston which opens and closes the dies is maintained constantly at a pressure of 200 lb. per sq. in., but instead of exhausting into the atmosphere it is exhausted into a 100-lb. pressure, the effective working pressure being thus 100 lb. Large savings in power said to be possible as the result of the use of air at high pressure constituted the principle reason for employing two pressures, and it is claimed that this system saves approximately 80 per cent of the horsepower.

The pressure or working end of the piston bears directly on the center of the movable half of the die. The stationary half of the die is attached to a suitable head mounted on four rods threaded for the adjustment of any size of die within the capacity of the machine. It is stated that the average time consumed in changing dies does not exceed 10 min.

Additional details of construction are described in the original article. It is stated that the original Dollin machine was installed at the plant of the Precision Casting Co., Syracuse, N. Y., with which the inventor was connected about five years ago, and has been in constant use since that time.

It is stated that 150 operations per hour have been obtained on aluminum castings; with lead alloys more than 300 an hour have been recorded, and with zinc alloys, more than 200. The output depends on the speed with which the die may be handled. The output may not exceed 10 or 15 an hour on large and difficult castings where the mold contains many cores, slides, or loose pieces, (Develop Die Casting Machine. E. C. Kreutzberg in *The Foundry*. vol. 51, no. 24, Dec. 15, 1923, pp. 1000–1001, 2 figs. Cf. also *Brass World*, vol. 19, no. 11, November, 1923, pp. 365–366, 2 figs., *d*)

HEAT TREATING

Salt Baths for Heat Treating

WHILE salt baths have been used for heat treating in the past, there were a number of problems that had to be solved before this process became fully commercial. In particular it was necessary to develop a bath that was not hygroscopic, did not fume, did not carbonize or decarbonize the work being treated, was stable in composition and absolutely non-poisonous. It is claimed that such a bath has now been developed. The salt bath is said to have certain important advantages as compared with either an oven furnace or a lead bath.

Curves in the original article give a comparison of the heating characteristics of tools in oven furnaces, salt baths, and lead pots. When a tool is put in an oven furnace or a lead pot it heats up rapidly at first on account of the great temperature difference between the tool and the furnace. This temperature difference decreases, however, as the tool is heated, so that the rate of heating gradually diminishes. An entirely different heating curve is obtained in the case of a tool heated in a salt bath having the correct physical constants. When the tool is first immersed in the bath a coating or jacket of solid salt freezes around it. This salt in the solid form is a rather poor conductor of heat and greatly retards the flow of heat into the tool. As the temperature of the tool rises the thickness of this jacket decreases, and finally the jacket disappears entirely when the tool has reached a temperature equal to the melting point of the bath, say, 1100 deg. fahr. In the meantime the temperature difference between the tool and the bath has also been decreasing and the rate of heating has been constant up to this point. From then on the temperature of the tool rises steadily to the temperature of the salt bath, say, 1400 deg. fahr.

One of the advantages of the salt bath is that it "wets" the tool, as a result of which a film of liquid salt forms on the tool and protects it from oxidation when it passes through the atmosphere on its way to the quenching tank. If the salt at working temperature has fluidity, this film will be very thin and the quantity of salt carried away from the bath on the work very small.

For hardening high-speed steel a bath had to be selected of such composition that lack of chemical activity at the high temperatures at which it is used would be insured. It is said that such a composition has been devised.

An important advantage of the salt bath for heat treating is the great accuracy of control over the hardening temperature. The temperature of a tool when it has come up to heat is exactly the same as that of a pyrometer fire end immersed in the same bath. This is not true in any furnace that does not make use of a thin-liquid heating medium. Thus the accuracy of the work is limited only by the accuracy of the pyrometer. (Value of Salt Baths for Heat Treating, Clifford B. Bellis, of Bellis Heat Treating Co., New Haven, Conn. *Forging-Stamping-Heat Treating*, vol. 9, no. 11, Nov., 1923, pp. 480–481, 3 figs., *d*)

INTERNAL-COMBUSTION ENGINEERING (See also Aeronautics)

How the World's Largest Diesel Was Built

THE story of constructing a marine engine which developed over 17,000 shaft hp., told by the Chief Engineer of the M.A.N. plant in Germany, where the work was done.

For this large engine the two-cycle type was selected mainly because of the great progress made in scavenging and supercharging the two-cycle cylinder.

As early as 1910 the question of developing a Diesel engine of large output was taken up at the Nuremberg shops of the M.A.N. and an experimental engine actually commenced. The cylinders of this engine were to develop 2000 b.hp. and were of the double-acting two-cycle type.

The most serious difficulty encountered in designing big engines of the Diesel type is the possibility of excessive temperature stresses. The first engine built at Nuremberg consisted of three cylinders 33.46 in. in diameter and 41.33 in. stroke. It was expected that 2000 b.hp. per cylinder could be developed at 150 r.p.m. Soon after starting the engine cracks appeared in the heads of the liners and at first they persisted, though the design was changed and different materials selected. As a result of experimental work extending over seven years a solution was found in an appropriate design employing only standard materials.

This experimental work was carried on until January, 1912, when an explosion in the scavenging-air pipe temporarily held up the work. Up to this time the maximum load obtained had been 5300 hp. (First installment of an article by Frederick Englert in *Motorship*, vol. 8, no. 12, December, 1923, pp. 848–849, 2 figs., *dh*)

Successful Conversion of a Hog Island A-Class Steamer to Motor Drive

THE Cramp Shipbuilding Company has converted the *Seekonk*, one of the Hog Island A-class steamers, to Diesel drive by equipping it with a long-stroke type of Burmeister and Wain engine, with the result of obtaining a measured fuel consumption of 0.292 lb. per i.hp-hr.

The *Seekonk* was a little better than the average of the six score vessels in her class. According to Shipping Board rating these boats are known as 7500-d.w.t. vessels. Actually, however, they seem to average closer to 7750 d.w.t.

The *Seekonk* with her oil-fired boilers, Curtis turbine, and single-reduction gear drive, would log about $10^1/_4$ or $10^1/_2$ knots on a daily fuel consumption of around 27 tons when loaded down to 21 ft., 22 ft., or even 24 ft., which is about what these ships draw with a good cargo. A difference of 2 ft. draft, either more or less, is absorbed in the average performance on a number of voyages, just like the weather or a little further dropping of turbine efficiency. All items, conditions, and circumstances rolled up together over a period of time gave as an average on a sea speed of $10^1/_4$ knots a fuel consumption of around 27 tons a day.

It is claimed that on the trial passage from Philadelphia to New York the same ship Diesel-engined at a sea speed of $10^3/_4$ knots consumed 7.3 tons per day, certainly an interesting difference from the fuel consumption on the steam drive.

The remainder of the article discusses the economy of operating motorized vessels of the same type as the *Seekonk* as compared with steam-driven vessels. Among other things, it is stated that there are more than 100 vessels of the Hog Island A-class available for purposes of conversion. Many of these boats can be bought from the Shipping Board at about $7 per ton, provided the purchaser will guarantee to convert the boat to oil-engine power. It is expected that Congress will authorize two-thirds of the value of the ship and cost of conversion to be loaned to domestic ship owners over a long period at moderate interest. (*Seekonk* Reduces Fuel Bill $30,000 per Year. *Motorship*, vol. 8, no. 12, December, 1923, pp. 834–836, 3 figs., *dp*)

The Bagnulo Engine and Gasifier

DESCRIPTION of a motor, preferably of the type intended for vehicle drive, operating entirely on heavier grades of fuel oils and doing away with the employment of gasoline or benzol for initial heating up.

One of the characteristic features of this engine is the fact that all the phases of the gasification cycle take place inside of the engine cylinder, and further the arrangement is such that the gasification process is expected to be completed previous to the beginning of the combustion stroke and the combustion proceeds in such a manner that it is at its peak at the beginning of the combustion stroke.

The gasifier of the Bagnulo motor (Fig. 2) consists essentially of the injection nozzle *B* and combustion chamber *K*. In this gasifier the fuel is not injected by a pump into a hot bulb in the usual manner but reaches the combustion chamber in the form of drops. These drops of fuel fall during the suction stroke into the hot combustion chamber *K*, where they are vaporized but cannot burn up on account of the fact that at that particular time the combustion-chamber space contains little air and is chiefly filled with residues of combustion from the preceding cycle. The fuel has plenty of time to attain complete vaporization and reaches the stage of combustion only at the end of the compression stroke when the amount of air sufficient for complete combustion is injected into the combustion chamber. Because of the fact that the fuel has plenty of time for complete vaporization during the suction and compression strokes, it is not necessary to employ preatomization.

In the upper third of the combustion stroke the beginning is made of establishing the proper ratio of mixture between air and fuel which leads to progressively increasing combustion, which increases still more with the very rapidly rising compression. The vaporization and compression assist each other in their development and both reach their peak condition at the moment when the piston reaches the end of its compression stroke. The maximum of thermodynamic output is reached therefore toward the end of the compression stroke, i.e., when the piston is at its upper dead center,

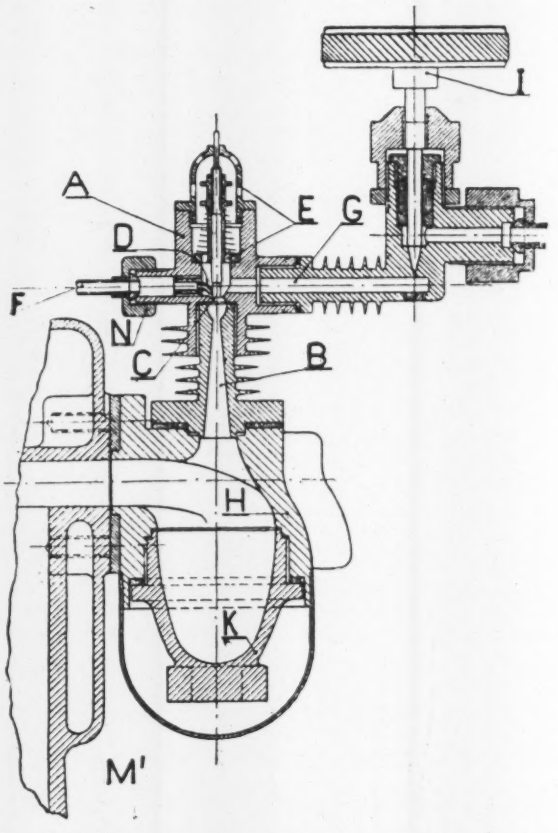


FIG. 2 BAGNULO HIGH-SPEED HEAVY-OIL ENGINE

which means that the Bagnulo engine permits of attaining high revolution speeds, in which respect it differs from other heavy-oil engines requiring fuel injection toward the end of the compression stroke. It is claimed that the higher r.p.m. and the more rapid and complete vaporization of fuel contribute to make this engine efficient and economical in fuel consumption. Further data on this engine will be published in an early issue. (Serial article, Der Bagnulo-Motor, in *Der Motorwagen*, vol. 26, no. 32/33, Nov. 20/30, 1923, pp. 460–461, 1 fig., *d*)

MACHINE TOOLS

A Straight-Bevel-Gear Generator

DESCRIPTION of a single-purpose machine brought out by the Gleason Works and designed for mass production. Its character-

istic feature is that the contour of teeth is developed by rolling the work and tool together at a uniform pitch-line velocity. The tools represent the adjacent teeth on a crown gear, and, as they reciprocate, cut away the stock on the work and so develop correct tooth profiles.

The generating motion is obtained by means of a crown gear and segment, the generating tool being entirely on the work-holding member. The index is operated by the generating roll.

The tool-carrying unit is mounted on an upright, which, instead of swinging about a center, is given a lateral movement by a cam to obtain the feed of the tools to the work. This permits the whole unit to be securely gibbed with simple adjustments for taking up the wear.

The clapper box is integral with the slide, and the tool holder and clapper block are made of steel, the tool holder being hardened and ground. The relief movement for the tools during the return stroke is effected mechanically and is positive.

The amount of movement necessary for the relief of the tools is exceedingly small, because the swivel pins on which the clapper blocks swing are behind the cutting edges of the tools and almost in line with their travel. This small movement makes the machine quiet and steady in operation and, as the drive for the tools is arranged to have the effect of a draw cut, the connection being well ahead of the tools, high tool speeds can be maintained practically without vibration or noise and the work produced has a smooth finish.

The tool-carrying slides are arranged to overrun the arms at both ends, so that a long run on any one job will not wear a depression in the bearing surfaces of either part. One large gib on each slide takes up the wear for all directions. The tools employed are the same as those used on the 11-in. and 18-in. Gleason generators. (*Automotive Industries*, vol. 49, no. 19, Nov. 8, 1923, pp. 958–959, 1 fig., *d*)

MACHINE SHOP (See Engineering Materials)

MARINE ENGINEERING (See Internal-Combustion Engineering)

MOTOR-CAR ENGINEERING

Bechereau and Siziare Bros. Automobile Chassis

DESCRIPTION of two unconventional chassis exhibited at the last Paris salon.

Bechereau, the designer of the first of the two, is a well-known airplane engineer and his chassis exhibits clearly the influence of aeronautical design.

In this chassis the wheels are independently suspended and are mounted on semi-axles attached to the central part of the chassis by means of ball-and-socket joints. As a result of this design the suspension may undergo a deformation without causing the tires to slide laterally on the ground. It reacts on the chassis both vertically and transversely through the intermediary of rubber "sandows" (heavy elastic strips). The mounting and adjustment of these "sandows" is very simple and they have been extensively used on airplanes, acting as shock absorbers. Excessive stretching of the "sandows" is held in check by oil dampers which consist of a piston moving in a straight-line cylinder.

The most characteristic feature of this chassis is, of course, the fact that spring suspension of the conventional type is eliminated. The same holds good to a certain extent of the Siziare chassis. Here, too, the wheels are independent and held at the ends of a transversal spring which is suspended from the center of the chassis. A strong longitudinal tube is provided to take up torsional stresses, in addition to which friction dampers are provided in the chassis.

The Siziare car also has a somewhat unusual steering system. The braking is on all four wheels and the brakes consist of flexible aluminum strips provided on the wearing surface with a bearing metal known under the name, "ferodo." They act on sheet-iron drums solidly attached to the wheels. (Nouveaux Chassis de Voitures Automobiles, *La Nature*, no. 2593, Dec. 15, 1923, pp. 379–381, 8 figs., *d*)

POWER-PLANT ENGINEERING

Maximum Commercial Efficiency of Steam Turbines and the Relation between Thermodynamic Efficiency and "K"

THE author defines maximum commercial efficiency of a turbine as the most practical combination of (1) power-weight ratio and (2) thermodynamic efficiency, which latter, in its turn, is a combination of efficiency ratio and steam consumption. High power-weight ratio implies low cost per kilowatt, and in order to attain it, it is necessary to work with:

1 High steam-jet velocities, in order to reduce the number of stages

2 High stresses, so as to run at the maximum permissible rotational speed, and minimize the size of the machine

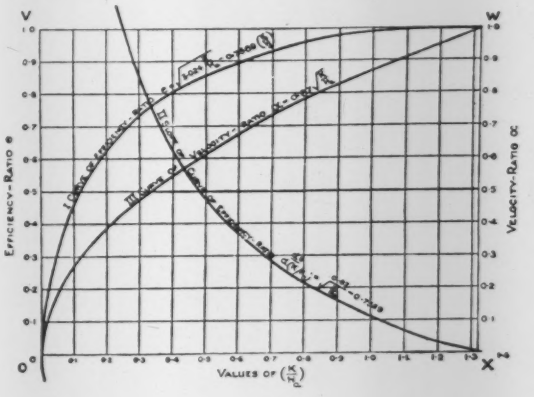
3 Moderate exhaust vacuum, so as to reduce the size of the exhaust end to a minimum

High efficiency ratio and low steam consumption together imply high thermodynamic efficiency, and in order to attain this it is necessary to have:

1 Many stages, in order to secure low jet velocities

2 High K, so as to run at a good overall velocity ratio

3 Fine clearances, so as to minimize the leakage losses



I. Curve of Efficiency-Ratio $e = \sqrt{3{\cdot}024\frac{K}{H_a}} - 0{\cdot}7569\left(\frac{K}{H_a}\right)$

II. Slope of Curve of Efficiency-Ratio

$$\frac{d}{d\,K/H_a}(e) = \frac{0{\cdot}87}{\sqrt{\frac{K}{H_a}}} - 0{\cdot}7569$$

III. Curve of Velocity-Ratio $\alpha = 0{\cdot}87\sqrt{\frac{K}{H_a}}$

FIG. 3

4 Large exhaust end, so as to utilize high vacuum as fully as possible

5 High initial superheat, so as to increase the available heat and reduce the number of stages working with wet steam.

It is clear that it is impossible to embody all these requirements in one and the same machine, so that it is necessary either:

1 To compromise all round, or

2 To develop some one or two desirable features to such an extent that they give a result so good that it is equal to, or better than, the best that can be attained by a general compromise.

It is always possible to effect a good all-around compromise and each type developed lends itself to a preference one way or another. The original article gives in the form of a table an interesting analysis of the losses in steam turbines. From this it would appear that the two governing considerations of design are the mean velocity ratio and the velocity coefficient of the nozzles and blading. The author proceeds next to show that the easiest and cheapest way of obtaining a high K (Parsons efficiency) is to run at high revolutions, which permits obtaining a good K without sacrificing power-weight ratio. It would appear, however, that what is really wanted from the viewpoint of high efficiency is a high velocity ratio in conjunction with low peripheral speeds, and these two together impose low steam-jet velocities.

The author claims that early turbines gave a remarkably good steam economy considering the very poor velocity ratio at which they worked, and he says that this may possibly be ascribed in no small measure to the fact that what small K they had was obtained largely by the great number of stages in conjunction with very low revolutions. In this way, while these turbines worked with a very poor velocity ratio, they also worked with very low steam-jet velocities, which would appear to have compensated to a marked degree for the former. The author illustrates this by a reference to the turbines of the *King Edward*, which was launched in 1901.

There is also another aspect of this question of jet velocity: it has to do with the effect of what may be termed the surface friction in the nozzles and blade passages of actual turbines. So far as these losses are known—from evidence furnished by impulse blading—the coefficient f varies approximately as bV^x, the index x being about 2.5 and V being the steam-jet velocity. Now, the loss in power developed by the turbine stages, due to this cause, is evidently proportional to $f \times V$, i.e., is proportional to $V^{3.5}$. But the total number of stages (n) in a pressure-compounded turbine is inversely as V^2, for $V^2/2g = J\,H_a/n$, or $V^2 = c/n$ for a given case, so that n varies as $1/V^2$. The length of blade, and therefore the "wetted" surface, also varies inversely as the velocity, so that the loss of power for the whole turbine will be proportional to:

$$V^{3.5} \times \frac{1}{V^2} \times \frac{1}{V} = V^{0.5}$$

That is, the higher the steam-jet velocities, the greater is the total loss, in spite of the fact that, by raising the steam velocities, the total number of stages is reduced.

The above is of course on the assumption that the blades have the same length of curved path over which the steam has to flow, throughout the turbine. In other words, it may be possible to cut down the losses of any given stage by reducing the length of the curved path, but only up to a certain point, beyond which the curvature becomes too abrupt for proper guidance of the steam as it is being deflected over the curved surfaces.

This discussion would seem to point to the desirability of low steam-jet velocities combined with high velocity ratio, and it follows that for a high efficiency ratio what is wanted is a turbine in which the requisite K is obtained by the number of stages rather than by revolutions or unnecessary large diameters. It will be seen that this requirement of good K by using many stages hardly coincides with the present tendency to obtain K by increased peripheral speeds, which, nevertheless, may reduce the cost per kw.

Next the author discusses the subject of inherent stage efficiency of the blading together with the losses occurring all the way down to the final coupling efficiency and he divides (admitting the distinction is not very scientific) all losses into inherent and incidental. By inherent are meant losses which are demonstrably present but which cannot as yet be eliminated, owing to lack of complete knowledge on the subject. Under this category may be placed nozzle and blade losses. Other serious sources of loss, such as steam leakage, may be cured more or less by the suppression of the leakage area and the pressure drop tending to cause the leakage. Another important source of loss, namely, the leaving loss at the final exhaust, is to a certain extent in the hands of the designer. He may cut it down in order to attain a high efficiency ratio or may tolerate it for the sake of high power ratio. From this point of view various types have to be handled in different ways.

For example, in the axial-flow reaction turbine, low peripheral speeds (at any rate in the high-pressure part of the machine) are inevitable owing to the impracticability of partial admission, and if, therefore, low peripheral speeds are deliberately incorporated in the design, in conjunction with adequate K, the circumstance of low jet velocity may be made to yield a very good efficiency ratio, as witness the evidence furnished by the Chicago machine, where the size of the unit gave reasonably good K and reasonably small leakage losses, even with the obsolete radial-clearance blading. Modern axial-clearance reaction blading enables very good economy to be attained in turbines of much smaller output, owing to the reduction in leakage losses.

In the double-rotation radial-flow reaction turbine, on the other hand, the high efficiency ratio attainable is presumably due to absolutely minimized leakage losses through the use of a multiplicity of packing. For it has been seen above that the reduced number of stages does not necessarily reduce the total surface friction loss, while in addition, in the double-rotation turbine, the jet velocities are considerably in excess of those commonly used in reaction turbine practice.

The single-rotation radial-flow turbine has not proved very successful, probably chiefly owing to poor K, and even in the double-rotation type it is not easy to get in very high K, because when the diameter of the outer ring of blades has been fixed by considerations of safe rotational stress, it is only possible to squeeze in a limited number of rings between it and the center of the machine, while at the same time the K value of each ring becomes progressively smaller, owing to the reduced diameter. The devices adopted, however, for successfully running with very fine clearances, enable the machine to give a good economical performance.

As regards the general relation between the thermodynamic efficiency and the total K, the author presents the theory by graphic representation. He finally obtains curve 2 in Fig. 3.

From this curve it will be seen, for example, that at a velocity ratio of 0.50, the rate of increase of K/H_a is 1.318 times the rates of increase of the efficiency ratio, while at 0.90 velocity ratio it is 15.4 times, or about 11.75 times more. It is easily seen from this that the attainment of higher efficiency ratio by means of increase of K for a given heat drop becomes more and more difficult as the peak of the curve is approached.

In the impulse turbine the theoretical value of the velocity ratio for maximum efficiency ratio is, of course, 0.50, which makes the curve much steeper, so that there is less latitude to work on, but halves the K required to reach the peak. In such turbines, nevertheless, the jet velocities commercially adopted range from 1000 to 1300 ft. per sec., throughout which range the nozzle efficiency apparently remains constant (at about 0.91), so that it is advisable to go right up to the theoretically best value of the velocity ratio, even if the requisite K is attained by raising the peripheral speed.

As regards the advantage that the impulse turbine has, theoretically, in requiring only one-half the total K that a reaction machine requires in order to reach a corresponding point on the efficiency-ratio curve, it should be borne in mind that if the former were rebladed (to take a hypothetical case) with reaction nozzles (or blading, as it is commonly called) in place of the impulse nozzles and blading, the overall velocity ratio would automatically be increased by $\sqrt{2}$, owing to halving of the available heat per stage, between the fixed and moving nozzles of each "reaction pair."

Thus, a velocity ratio of 0.50 for the impulse machine would become 0.71 after the conversion.

On the other hand, the impracticability of working on a constant mean diameter in a reaction turbine necessitates an increase in the total number of stages, so that the value of the above circumstance is considerably vitiated, but against this must be placed the fact that an impulse "pair" requires more room axially than a reaction pair, and in practice it is quite a commercial proposition to incorporate K is an axial-flow reaction turbine to reach any desired point on the efficiency-ratio curve. (Robert Dowson in *Beama*, vol. 13, no. 68, December, 1923, pp. 359–365, 2 figs., *tA*)

STEAM ENGINEERING (See Power-Plant Engineering)

STRENGTH OF MATERIALS

Stresses in Certain Welded and Riveted Tanks Tested Under Hydrostatic Pressure

FOR the purpose of ascertaining the relative merits of riveted as compared with welded pipes the Riter-Conley Company designed and constructed four steel tanks for test, this form having been selected because it was desired to apply the results to penstock construction. The tests were carried out at the Bureau of Standards. Only the following conclusions can be reported here.

The results of the analysis of the deformation and distribution of stress in these tanks appear to warrant the following general conclusions:

Deformations and Stresses. The commonly accepted theory for the design of tanks is, for all practical purposes, sufficiently accurate,

provided the computed stresses are not influenced by secondary stresses.

For thin tanks, the measured stresses, based upon the two-dimensional formula, are in close agreement with the design stresses computed by the common pressure formulas, provided the former are not affected by secondary causes. This is borne out by the results obtained at the center of the end.

Secondary stresses, resulting in high stress intensity, were caused by (*a*) faulty design of the attachment of the spherical end of the cylindrical shell, (*b*) non-conformity of the shell to an accurate circular section, and (*c*) discontinuities in the shell for the manhole and fittings. These may produce a possibly dangerous condition if present near a welded or riveted joint or seam.

Stresses were increased by the presence of a seam.

Mechanical Details and Recommendations. Poor welding and calking were responsible for the premature failure of two of the tanks tested.

Failure of the two remaining tanks showed that the attachments were not able to withstand the high stresses caused by cutting openings in the plate. The results of these tests do not warrant preference to be given to any one of the tanks.

With more careful workmanship these tanks can be made, having a factor of safety of two or higher, for a working stress of 16,000 lb. per sq. in. in the plate.

All welded tanks should be proof-tested to at least their working load and leaks repaired by cutting out the defective places in the seams and rewelding. Where the failure of a high-pressure tank would have serious consequences, such tanks should be proof-tested to at least twice their working pressure.

The ends should have a transition curve between the spherical portion and the shell, or sufficient reinforcement provided to reduce the high stresses. The joint or seam uniting the end and the shell should be placed well back on the shell, outside the region of bending caused by deformation of the end under internal pressure. (A. H. Stang and T. W. Greene in *Bureau of Standards Technologic Paper*, no. 243, Oct. 13, 1923, pp. 645–666, 11 figs., *e*)

TESTING AND MEASUREMENTS

Dynamometer-Car Test—Thermic-Siphon Test

A DYNAMOMETER-CAR TEST ON THE N. C. & ST. L. RAILWAY. Description and data of tests of a thermic siphon made by the Nashville, Chattanooga and St. Louis Railway.

The tests were primarily intended to determine precisely the value of the thermic siphon on locomotives (as to this device compare MECHANICAL ENGINEERING, vol. 41, no. 3, March, 1919, pp. 284–285, and vol. 44, no. 6, June, 1922, pp. 390–391). As the thermic siphon is an integral part of the locomotive, it is not easy to segregate the data for the purpose of strictly comparative tests.

There were many comparative tests carried out on siphon-equipped locomotives and locomotives of the same type not equipped with siphons. Such tests were, however, subject to criticism on the ground that the locomotives tested might have had individual characteristics which influenced the results.

In the present tests arrangements were made to observe the effect of the siphon on the same locomotive as previously tested without the siphon. It was arranged, therefore, to place siphons in the Mikado-type locomotive tested last spring without siphons and to test the performance of this locomotive under as nearly identical operating conditions as possible.

The theoretical cylinder capacity of locomotive 651 is 2434 hp. This was not altered with the addition of the two thermic siphons, but applying Cole's ratios to the boiler and firebox, it is noted that the theoretical capacity of the boiler prior to the addition of the siphons was 2350 hp. By the installation of two thermic siphons in place of two of the arch tubes, the capacity of the boiler was increased to 2490 hp. In other words, the application of siphons to locomotive 651 increased the horsepower of its boiler from 96 per cent to 103 per cent of the theoretical horsepower of the cylinders. This improved capacity ratio and the increased water circulation throughout the boiler created by the siphons are the fundamentals upon which an improvement in boiler efficiency is predicted. This improvement in boiler efficiency can either be realized through a reduction in the quantity of fuel required to evaporate a given quantity of water or by an increase in the quantity of steam generated with the same quantity of fuel. If the locomotive is already being worked up to its maximum steaming capacity, an increase in boiler efficiency would either result in an increased output without a corresponding increase in fuel or a reduction in fuel with the same locomotive output, assuming that the engine efficiency remained constant. While increased locomotive output represents the most attractive possibility with any improvement in boiler efficiency and is the result most generally sought after, the reduction in fuel accomplished with a uniform locomotive output affords a more reliable measure of the gain in efficiency. In the tests recently concluded on the N. C. & St. L. Ry. no attempt was made to develop the limits to which the steaming capacity of the boiler could be forced with and without the siphons, the observations being confined to the performance of the locomotive under approximately operating conditions.

The locomotive was tested first without siphons in three complete runs between Nashville and Chattanooga involving some rather heavy grades. It was then equipped with two thermic siphons but no other work was done on it. It was then tested in three round trips over the same track but with a heavier load. The tests without siphons were carried out in March and with siphons in September, proper weight being placed on the seasonal difference in temperature and rail conditions.

Comparison of the actual work performed as shown by the dynamometer-car records shows that the hourly drawbar-horsepower rate on the northbound runs was actually 7.97 per cent less with the siphon-equipped locomotive and 8.13 per cent less on the southbound runs with this locomotive. On the other hand, the locomotive was evidently not run at as economical cut-offs when tested with the siphon since the reduction in the average steam consumption per hour on the southbound runs with this equipment was only 2.45 per cent, while on the northbound runs the average steam consumption per hour was 3.41 per cent less on the tests with the siphon-equipped locomotive than on the previous tests of locomotive 651 without this equipment. Under these conditions it is noted that on the northbound runs the equivalent evaporation in pounds of water per pound of coal was 11.69 per cent higher with the siphon equipment, and on the southbound runs it was 11.61 per cent higher in the siphon-equipped locomotive. The average increase in equivalent evaporation on the siphon-equipped locomotive as compared with the non-siphon locomotive was 11.65 per cent. In the tests of locomotive 651 both with and without the siphons, the locomotive was fired throughout the tests with a Duplex mechanical stoker which was operated by the same traveling fireman on all runs.

The average boiler pressure maintained during the tests of locomotive 651 without siphons was 191.7 lb. and in the subsequent tests with siphons the average boiler pressure recorded was 191.0. The average temperature of the steam entering the cylinders on the test without siphons was 588 deg. fahr. and the temperature maintained on the tests with the siphon averaged 587.9 deg. fahr. The highest steam temperature recorded on both tests was 620 deg. fahr. To further illustrate the uniformity of conditions under which locomotive 651 was tested with and without siphons, the *Railway Review* has condensed two typical sections from the dynamometer-car records of the performance of this locomotive over the same profile with and without siphons. The steam pressures and temperatures recorded on this portion of the runs with and without equipment are also plotted on this condensed record, which demonstrates that the installation of two thermic siphons in the firebox of locomotive 651 had no noticeable effect upon the temperature of the superheated steam. (*Railway Review*, vol. 73, no. 15, Oct. 13, 1923, pp. 521–526, 8 figs., *ec*)

WELDING (See Strength of Materials)

CLASSIFICATION OF ARTICLES

Articles appearing in the Survey are classified as *c* comparative; *d* descriptive; *e* experimental; *g* general; *h* historical; *m* mathematical; *p* practical; *s* statistical; *t* theoretical. Articles of especial merit are rated *A* by the reviewer. Opinions expressed are those of the reviewer, not of the Society.

Proposed Rules for the Inspection of Material and Boilers

Preliminary Report of Sub-Committee of A.S.M.E. Boiler Code Committee on Rules for the Inspection of Material and Boilers

THIS report of the Sub-Committee of the Boiler Code Committee on Rules for the Inspection of Material and Boilers was, after nearly four years of preliminary investigative and research work, completed and submitted for discussion at a public hearing held in connection with the Spring Meeting of 1923, at Montreal, Que. This Sub-Committee has coöperated actively with the American Boiler Manufacturers Association and other interested organizations in order to properly cover the field, and as a result the comments received at the public hearing were very limited in number.

This report, which is intended to form a section of the A.S.M.E. Boiler Code, is divided into two parts, the first dealing with new boilers, and the second with installed boilers. It was formulated by a Sub-Committee of the Boiler Code Committee appointed on July 31, 1918, as follows:

CHAS. S. BLAKE, *Chairman*	W. P. EALES
S. H. BARNUM	CHAS. E. GORTON
L. E. CONNELLY	F. W. HERENDEEN
F. G. COX	JAMES PARTINGTON.

It is the request of the Committee that these proposed rules be fully and freely discussed so that it may be possible for any one to suggest changes before the rules are brought to final form and presented to the Council for approval. Discussions should be mailed to C. W. Obert, Secretary of the Boiler Code Committee, 29 West 39th St., New York, N. Y., in order that they may be considered by the Boiler Code Committee.

Proposed Rules for the Inspection of Material and Boilers

Part I—New Work

I–1. It is understood that in every detail careful examination shall be made by the inspector of all material and workmanship without being specifically directed by each rule. The inspector shall rely upon the rules of the A.S.M.E. Boiler Code for boiler construction wherever they are applicable. Reference hereinafter made to the "Code" shall mean the "A.S.M.E. Boiler Code."

I–2. General Inspection of Material. Surface inspection of rivets, steel bars, steel castings, gray-iron castings, malleable castings, staybolt material, brace bars, tubes and all other material for Code boilers shall preferably be made by the inspector who is to make the inspection of the completed boilers. Material having injurious defects as referred to or defined in the Code shall be rejected. This inspection shall be made when practicable before the material is used.

I–3. Inspection of Plate Material. The inspection of plate material to be used in a boiler to be constructed in accordance with the Code shall include the identification of the material by checking the manufacturer's test identification numbers, found on all plates, with the numbers given on the mill-test report as certified to by the manufacturer of the material.

I–4. Statement of Physical and Chemical Properties. The inspector shall satisfy himself that all material used in the manufacture of a boiler is in accordance with the Code requirements, and if he desires he may secure from the manufacturer a written statement to the effect that it is, to the best of his knowledge and belief, in accordance with the Code. All parts shall be examined whenever possible before they are assembled as well as after they are applied.

I–5. Stamps on Plates. The inspector shall see that plates are properly stamped before being used. Should the identifying marks be obliterated or plates separated into two or more parts in the process of work, he shall see that such marks are properly transferred under Code requirements.

I–6. Measuring Plates. All material shall be gaged or measured to determine whether the thickness meets with the Code requirements, due allowance being made for Code variations.

I–7. Inspection During Manufacture. During the process of manufacturing a boiler, the material shall be inspected for surface defects, cracks, blisters, pit marks, blowholes, or any other defects liable to develop in fabrication, and for excessive hammer marks. If defects are sufficient to materially impair the strength, the boiler shall not be stamped with the Code symbol.

I–8. Inspections of and Allowances for All Plates Subject to Pressure. All plate material shall be examined for surface defects such as scale depressions and laminations. If depressions are found, careful measurement shall be made, and if by reason of the reduced thickness, the plate is not weaker than where machined for rivet holes or tube holes, it may be accepted, provided that in no case shall a plate be accepted having a depression greater than 15 per cent of its thickness and not exceeding 4 in. in its greatest length. Plates that are found laminated shall be rejected.

I–9. Curvature of Plates and Straps. The inspector shall see that butt straps and the ends of shell plates forming the longitudinal joints shall be rolled, or formed to the proper curvature by pressure, as required by the Code.

Cylindrical shapes shall be rolled or formed to as nearly a perfect circle as is practicable.

I–10. Plate Beveling and Calking. Calking edges of plates shall be beveled in accordance with the Code and shall be even and free from ragged edges. Examination of the beveling shall be made before the calking. Calking shall be evenly and carefully done in accordance with the Code.

I–11. Fitting Cylindrical Courses. The inside circumference of an outside course shall not exceed the outside circumference of the inside course or head by more than $1/4$ in., the circumferences to be measured before being bolted together.

The space between the edges of the ends of the plate when rolled and bolted together for butt-strap riveting shall not exceed $1/4$ in.

I–12. Punching, Reaming, or Drilling Rivet Holes. When rivet or tube holes are punched, they shall be inspected before and after reaming to determine whether they have been reamed in accordance with Code requirements. When the holes are drilled from the solid the inspector shall satisfy himself that the work is so done.

I–13. Tolerance for Rivet Holes. The maximum diameter of finished rivet holes shall not exceed the nominal diameter of the rivet when cold by more than $1/16$ in. For rivets up to $7/8$ in., it is preferable to limit the hole to $1/32$ in. larger than the cold rivet.

I–14. Fitting Straps. Butt straps shall be applied as provided for in the Code. All details of fitting straps and removing burrs shall be carefully followed.

I–15. Treatment of Rivet Holes after Reaming. The inspector shall see that all rivet holes in joints, lugs, braces, etc., are in accordance with the Code, are of proper size before and after reaming, and burrs, chips and turnings removed.

I–16. Pressure on Bull-Driven Rivets. Bull-driven rivets shall have from 100 to 150 tons pressure exerted for each square inch of cross-sectional area of the rivet after driving.

I–17. Rivet Heads. Rivets shall be of sufficient length to completely fill the rivet holes, and so driven as to give a full rivet head without showing excessive depression in the sheet from the dies. The head formed by the rivet manufacturer and the head formed by the boiler manufacturer shall be in accordance with the Code.

No rivet head shall have an eccentricity of more than 20 per cent of the diameter of the cold rivet shank.

I–18. Inspection of Tubes before Use. Tubes shall be examined for surface defects and so far as possible shall be free from depressions caused by scale or scoring. Code tolerances in gaging shall not be exceeded.

I–19. Tube-Hole Tolerance and Use of Ferrules. The diameter of finished tube holes shall not exceed the nominal diameter of the tubes by an amount greater than shown in the following table:

	In.
Fire end of fire-tube boilers	1/32
Opposite end of fire-tube boilers	1/16
Water-tube boilers	1/32

If ferrules are used, proper allowance should be made for the thickness of ferrule. Rough and sharp edges of the tube holes shall be removed as required by the Code.

I–20. Flaring and Beading Tube Ends. After tubes are set the inspector shall examine their ends to see that they are properly rolled or expanded and properly beaded, flared, or welded, the beading as required by the Code.

I–21. General Flanging. The inspector shall see that in flanged sections there are no cracks due to the flanging operation, no deep hammer marks, burned sections, scars, or other injurious surface defects. It is to be noted that reduction in thickness is not below the designed thickness at the heel of the flange, and that the flanged section is practically true to form as designed. When flanged manholes are used the corners shall be well rounded to a radius not less than that specified in the Code. The manhole flange and reinforcing ring shall, when used, be installed in accordance with the Code.

I–22. Flanged Furnace Openings or Flanged Door Rings. Flanged furnace openings and flanged door rings shall be properly heated and properly laid up before drilling rivet holes.

I–23. Staying of Flat Surfaces. All flat surfaces shall be straight and held in place and kept in position until the stays are fitted. In case of threaded staybolts, the threads of the bolts and tapped holes shall be cut clean and fit snug as far as practical. The ends of the staybolts shall extend through the plates a sufficient distance on each side to be properly and neatly riveted over. If staybolts are laminated or brittle they must be rejected.

I–24. Fitting Braces or Stays. Riveted diagonal braces or stays in boilers shall be properly heated and fitted. Braces or stays of any type must have correct and even tension.

I–25. Crown Bars. Crown bars shall be fitted and stayed and shall bear evenly and rest firmly upon their supporting members.

I–26. Alignment of Handholes or Plugs. When the openings of handholes or plugs are to be used for the removal of tubes, they shall register with the tube holes in such manner that the tubes may be removed and replaced without damage to the tubes or the holes.

I–27. Location of Handholes, Manholes, and Washout Openings. The number and location of handholes, manholes, and washout openings shall conform to the Code.

I–28. Cast Material. All cast parts when ready for use shall be carefully examined to determine that the walls are not less than the designed thickness, free from injurious defects, and annealed as required by the Code.

I–29. Fitting Attachments. All lugs, brackets, nozzles, flanges, manhole frames, and other appurtenances shall fit snugly and conform to the curvature of the shell, or surface to which they are attached.

I–30. Openings for Fittings. The inspector shall see that the water column, safety valve, blow-off openings, etc., are of proper size and location as required by the Code.

I–31. Location of Fusible Plugs. The inspector shall see that fusible plugs when used, are located in accordance with the Code.

I–32. To Determine the Radius of a Dished Head. To find the radius of a convex head, let

R = radius of dish

C = chord or distance straight across between two points on the inner surface of the head (see note).

H = distance from the middle point of chord C to the inner surface of the head, measured at right angles to the chord.

then

$$R = \frac{H}{2} + \frac{C^2}{8H}$$

NOTE: The distance C should be taken as large as practicable, but small enough so that no portion of the rounded surface at A, which joins the flange and the dished portion of the head will be included in the measurements (See Fig. I–1).

I–33. Inspection During Construction. The inspector shall examine all parts of the boilers during construction to determine that all the material and workmanship comply with the Code and these rules.

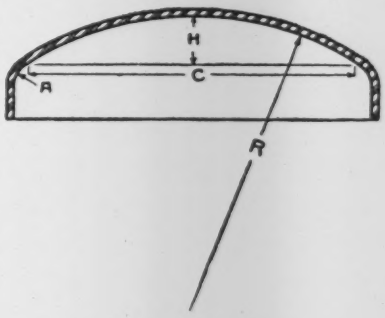


FIG. I–1

I–34. Hydrostatic Test. When a boiler is completed or part of an incomplete boiler is ready for hydrostatic test, it shall be filled with water of a temperature not less than that of the temperature of the surrounding atmosphere. All air shall be allowed to escape so that water will come in contact with all parts that are assembled and the pressure shall be slowly raised until it meets with the Code requirements for the type under test and shall be held constant long enough to enable the inspector to examine all visible parts in order to determine the quality of the workmanship and the safety of the entire structure.

If any leak is developed which may be stopped without excessive calking or rolling, the boiler or part under test may be accepted when made tight, but if there are leaks which cannot be stopped by reasonable calking or rolling, the defective part or parts must be replaced.

I–35. A.S.M.E. Code Stamp. Before a boiler is stamped, the inspector shall ascertain that the manufacturer has properly secured a stamp, with the A.S.M.E. symbol, from the Society and when a boiler or part of a boiler has been fully tested and ready for the identifying marks, they shall be applied as required by the Code and care should be exercised to have the marking distinct and durable.

I–36. Inspection at Place of Installation. Boilers shipped in parts for assembly at the place of installation shall have, in addition to the examination in process of manufacture at the shop, a further hydrostatic test and inspection to determine whether the work of assembling is done in accordance with the Code requirements. This will also necessitate observation as to boiler supports, free expansion of the drums, legs and other parts.

When an inspection is made at the place of installation, irrespective of the type of boiler, the inspector shall ascertain further whether the safety and other valves, water column, gage cocks, and steam gages, or other apparatus meet the Code requirements.

I–37. Record of Completed Boiler. When the shop hydrostatic test has been completed and the boiler is found acceptable as an A.S.M.E. Code boiler, its full dimensions and record of material shall be taken by the manufacturer, recorded on data sheet, certified to by the inspector as being correct, and a copy of the record shall be retained by both.

Part II—Rules for the Inspection of Installed Boilers

I–38. General Instructions. It is essential to have every part of a boiler that is accessible, open and properly prepared for examination, internally and externally. All boilers have openings through which an examination may be made and which for operation are closed; all such parts shall be opened whether for access to water surfaces or heat surfaces. In cooling a boiler down for inspection or repairs, the water should not be withdrawn until the setting is sufficiently cooled to avoid damage to the boiler, and when possible allowed to cool down naturally. It is not necessary, in order to comply with ordinary prudence, to remove insulation material, masonry or fixed parts of the boiler, unless defects or deterioration peculiar to certain types or inaccessible parts of boilers are sus-

pected. Upon sufficient visible evidence or suspicion due to age or other causes, every effort shall be made to discover the true condition, even to the removal of insulating material, masonry or fixed parts of a boiler. Sometimes drilling or cutting away of parts is justifiable and necessary to positively determine this condition.

The inspector shall get as close to the parts of the boiler, both internal and external, as is practicable, in order to get the best possible vision of the surfaces, and use a good artificial light if natural light is not sufficient. Whenever attachments or apparatus require testing, the tests shall be made by a plant operative in the presence of the inspector, unless otherwise desired.

I–39. Scale, Oil, Etc. Upon entering a boiler, the inspector shall examine all surfaces of the exposed metal to observe the action caused by the use of water, oil, scale solvents, or other substances which may have intentionally or unintentionally gone in with the feedwater. Any evidence of oil shall be carefully noted. The smallest amount of oil is dangerous and immediate steps shall be taken to prevent any further entrance of oil into the boiler. Oil or scale in the tubes of water-tube boilers or on plates over the fire of any boiler is particularly bad, often causing them to rupture.

I–40. Corrosion, Grooving. A given amount of corrosion along or immediately adjacent to a seam is more serious than a similar amount of corrosion in the solid plate away from the seams. Grooving along longitudinal seams is especially significant as grooving or cracks are likely to occur when the material is highly stressed. Severe corrosion is likely to occur at points where the circulation of the water is poor and such places should be examined most carefully for evidences of corrosive action.

For the purpose of estimating the effect of corrosion or other defects upon the strength of a shell, comparison shall be made with the efficiency of the longitudinal riveted joint of the same boiler, the strength of which is always less than that of the solid sheet.

All flanging shall be thoroughly inspected and particularly the flanges of circular heads that are not stayed. Internal grooving in the fillet of such heads and external grooving in the outer surfaces of heads concave to pressure is very common since there is a slight movement in heads of this character which produces this kind of defect. Some types of boilers have what is known as the ogee or reversed flange construction in some of their parts that may be inaccessible to the eye, but the condition shall be determined by the insertion of a mirror which at a proper angle will reflect back to the eye the condition of such a place, or any other feasible manner.

I–41. Stays. All stays, whether diagonal or through, shall be examined to note that they are in even tension. All fastened ends shall be examined to note whether cracks exist where the stays are punched or drilled for rivets or bolts, and if not found in proper tension, the inspector should recommend their proper adjustment.

I–42. Manholes and Other Openings. The manhole and other reinforcing plates, as well as nozzles or other connections flanged or screwed into a boiler, shall be examined internally as well as externally, to see that they are not cracked or deformed, and wherever possible observation shall be made from the inside of the boiler as to the thoroughness with which its pipe connections are made to the boiler. All openings to external attachments shall be noted to see that they are free from obstructions, such as water-column connections, openings in drypipes and openings to safety valves.

I–43. Fire Surfaces—Bulging, Blistering, Leaks. Particular attention shall be given to the plate or tube surfaces exposed to the fire. The inspector shall observe whether any part of the boiler has become deformed during operation by bulging or blistering; the former is a distortion of the entire thickness of the plate or tube where it takes place, while the latter is a lamination or separation of the plate due to foreign material being embedded in the ingot before the plate is rolled. If bulges or blisters are of such size as would seriously weaken the plate or tube, and especially when a leakage is noted coming from those defects, the boiler shall be discontinued from service until the defective part or parts have received proper repairs. Careful observation shall be made to detect leaking from any portion of the boiler structure, particularly in the vicinity of seams and tube ends. Fire tubes sometimes blister but rarely collapse; the inspector should look through the tubes for such defects and if they are found with a sufficient degree of distortion they should be removed.

I–44. Lap Joints, Fire Cracks. Lap-joint boilers are apt to crack where the plates lap in the longitudinal or straight seam; if there is any evidence of leakage or other distress at this point, it shall be thoroughly investigated, and if necessary, rivets removed or the plate slotted in order to determine whether cracks exist in the seam. Any cracks noted in shell plates are usually dangerous except fire cracks that run from the edge of the plate into the rivet holes of girth seams. A limited number of such fire cracks is not usually a very serious matter.

I–45. Testing Staybolts. The inspector shall test staybolts by tapping one end of each bolt with a hammer and when practicable a hammer or other heavy tool should be held on the opposite end to make the test more effective.

I–46. Tubes—Their Defects, Etc. *a* Tubes in horizontal fire-tube boilers deteriorate more rapidly at the ends toward the fire, and they should be carefully tapped with a light hammer on their outer surface to ascertain whether there has been serious reduction in thickness. The tubes of vertical tubular boilers are more susceptible to deterioration at the upper ends when exposed to the products of combustion without water protection. They should be reached as far as possible either through the handholes, if any, or inspected at the ends.

b The surfaces should be carefully examined to detect bulges or cracks, or any evidences of defective welds. Where there is a strong draft the tubes may become thinned by erosion produced by the impingement of particles of fuel and ash, or the improper use of soot blowers. A leak from a tube frequently causes serious corrosive action on a number of tubes in its immediate vicinity.

c Where short tubes or nipples are employed in joining drums or headers, there is a tendency for waste products of the furnace to lodge in the junction points and such deposits are likely to cause corrosion if moisture is present. All such places should be thoroughly cleaned and examined.

I–47. Ligaments between Tube Holes. The ligaments between tube holes in the heads of all types of fire-tube boilers and in shells of water-tube boilers should be examined. If leakage is noted, it may denote a broken ligament.

I–48. Steam Pockets. Steam pockets on fire surfaces are sometimes found in new or replacement work and wherever this is possible or likely, the inspector should make observation and if found, recommend the necessary changes.

I–49. Pipe Connections and Fittings. The steam and water pipes, including connections to the water column, shall be examined for leaks, and if any are found it should be determined whether they are the result of excessive strains due to expansion and contraction, or other causes. The general arrangement of the piping in regard to the provisions for expansion and drainage, as well as adequate support at the proper points, shall be carefully noted. The location of the various stop valves shall be observed to see that water will not be pocketed when the valves are closed and thereby establish cause for water-hammer action.

The arrangement of connections between individual boilers and the main steam header shall be especially noted to see that any change of position of the boiler, due to settling or other causes, will not produce an undue strain on the piping.

It shall be ascertained whether all pipe connections to the boiler possess the proper strength in their fastenings, whether tapped into the boiler, a fitting, or flange riveted to the boiler. The inspector shall determine whether there is proper provision for the expansion and contraction of such piping, and that there is no undue vibration tending to crystallize the parts subjected to it. This includes all steam and water pipes; and especial attention should be given to the blow-off pipes with their connections and fittings, because the expansion and contraction due to rapid changes in temperature and water-hammer action create a great strain upon the entire blow-off system, which is more pronounced when a number of blow-off pipes are joined in one common discharge. The freedom of the blow-off connection on each boiler shall be tested whenever possible by opening the valve for a few seconds, at which time it can be determined whether there is excessive vibration. Blow-off pipes should be free from external dampness to prevent corrosion.

I–50. Water Column. The piping to the water column shall be carefully noted to see that there is no chance of water being

pocketed in the piping forming the steam connection to the water column. The steam pipe should preferably drain toward the water column. The water pipe connection to water column must drain toward the boiler.

The relative position of the water column with the fire surfaces of the boiler shall be observed to determine whether the column is placed in accordance with the Code. The attachments shall be examined to determine their operating condition.

If examination is made with steam on the boiler, the water columns and gage glasses shall be observed to see that the connections to the boilers are free as shown by the action of the water in the glass. The water columns and gage glasses shall be blown down on each boiler to definitely determine the freedom of the connections to the boiler, as well as to see that the blow-off piping from the columns and water glasses are free. The gage glasses shall be observed to see that they are clean and that they are properly located to permit ready observation. The freedom of the gage cocks shall be determined by test.

I-51. Baffling—Water-Tube Boilers. In water-tube boilers, it should be noted, as far as possible, whether or not the proper baffling is in place. In many types of boilers the absence of baffling often causes high temperatures on portions of the boiler structure which are not intended to be exposed to such temperatures, from which a dangerous condition may result. The location of combustion arches with respect to tube surfaces shall be carefully noted. These are sometimes arranged so as to cause the flame to impinge on a particular part of a boiler and produce overheating of the material and consequent danger of rupture of the part.

I-52. Localization of Heat. Localization of heat brought about by improper or defective burner or stoker installation or operation creating a blowpipe effect upon the boiler, shall be condemned.

I-53. Suspended Boilers—Freedom of Expansion. Where boilers are suspended the supports and setting shall be carefully examined especially at points where the boiler structure comes near the setting walls or floor. Often accumulation of ash and soot bind the boiler structure at such points and produce excessive strains on the structure owing to the expansion of the parts under operating conditions.

I-54. Safety Valves. As the safety valves are the most important attachments upon the boiler, they shall be inspected with the utmost caution. There should be no accumulations of rust, scale or other foreign substances located in the casings so as to interfere with the free operation of the valves. The setting and freedom of the safety valves should be tested preferably by raising the steam pressure to the blowing off point, or if this cannot be done, the valves shall be tested by means of the try-levers to ascertain if they are free. Where the steam discharged from a safety valve is led through a pipe, the inspector shall determine at the time the valve is operating, whether or not the drain opening in the discharge pipe is free and in accordance with the Code.

If the inspector deems it necessary, in order to determine the freedom of discharge from a safety valve, the discharge connection should be removed. Under no circumstances should a stop valve be permitted between a boiler and its safety valve.

I-55. Steam Gages. The steam gages on all boilers shall be removed and the inspector shall test them and compare their readings with a standard test gage. The readings of the steam gages shall be observed and compared when making an inspection with steam on the boiler, where several boilers are in service connected to a common steam main. The location of the steam gage shall be noted to see whether or not it is exposed to high temperature either externally, as would be the case if placed close to the smoke flue or other highly heated part of the boiler or setting, or exposed to heat internally due to lack of protection of the gage spring with a proper siphon or trap to prevent steam from coming in contact with the spring. The inspector shall see that provisions are made for blowing out the pipe leading to the steam gage.

I-56. Changes from Code Requirements. At each inspection of a boiler, observation should be made to determine whether changes or departures from Code requirements have taken place since previous inspection was made.

I-57. Imperfect Repairs. Repairs are frequently improperly made, especially tube replacements. When repairs have been made, the inspector shall observe whether the workmanship is properly and safely done.

Excessive rolling of tubes, where they are easy of access, is a common fault of inexperienced workmen. On the contrary, when the tube end is difficult to reach and observe the extent of rolling, they are frequently underrolled, from which inefficient rolling separation of the parts is almost inevitable.

I-58. Hydrostatic Pressure. When there is a question of doubt about the extent of a defect found in a boiler, the inspector, in order to more fully decide upon its seriousness, should cause the application of hydrostatic pressure under the Code provisions.

I-59. If the inspector is to determine the safe working pressure of installed boilers, he shall take such data from the boiler as will enable him to estimate its original strength with which to compare deterioration due to age and use and fix the allowable working pressure in accordance with the rules for Existing Installations.

I-60. Suggestions. There are certain rules which should be followed irrespective of the type of boiler to be inspected. The inspector, whether he is the employee of a state, municipality or insurance company, should be well informed of the natural and neglectful causes of defects and deterioration of boilers. He should be conscientious and extremely careful in his observations, taking sufficient time to make the examinations thorough in every way, taking no one's statement as final as to conditions not observed by him, and in the event of inability to make thorough inspection, he should note it in his report and not accept statements of others.

The inspector shall make a general observation of the condition of the boiler room and apparatus, as well as of the attendants, as a guide in forming an opinion of the general care of the equipment.

He shall weigh very carefully the condition of any defects in order to determine its relation to, or influence upon, the safety of the inspected boiler. He shall question responsible employees as to the history of (old) boilers, their peculiarities and behavior, ascertain what, if any, repairs have been made, and if any, their character, and he shall investigate and determine whether they were properly and safely made.

Revisions

PAR. 212*d:* MODIFY PROPOSED REVISION OF PAR. 212*d* AS PUBLISHED IN THE JULY, 1922, ISSUE OF MECHANICAL ENGINEERING, TO READ AS FOLLOWS;

d Furnaces over 38 in. in outside diameter and combustion chambers not covered by special rules in this Code, which have curved sheets subject to external pressure, that is, pressure on the convex side, both the circumferential and longitudinal pitches of the staybolts shall not exceed 1.05 times that given by the formula in Par. 199.

The stress per sq. in. in staybolts shall not exceed 7500 lb., based on a total stress obtained by multiplying the product of the circumferential and longitudinal pitches by the maximum allowable working pressure.

Discarded Boiler Tubing Salvaged by Welding

THE use of the welding and cutting torch for salvaging scrap boiler tubing is described in *Power* for January 1, 1924. The salvaged tubing is put into service again in the form of welded pipe lines carrying oil, gas and low-pressure steam. In one case large quantities of scrap four-inch boiler tubing are being installed as part of a 28-mile welded gas line. In general the operation consists of cutting off the split or corroded ends, straightening such tubing as may be bent or deformed, building up pitted places, and welding comparatively short lengths of pipe tubing into 30-ft. or 40-ft. sections for convenient and economical handling in the field. In some cases where large quantities of this tubing are being reclaimed, the operation of cutting the damaged end of the tube has been standardized by the use of specially built tables and racks, and guides for both the pipe and the cutting blow-pipe. For example, in one place the cutting blowpipe is held in a rack and the pipe turned by a helper. When it is desired to cut the pipe ends so they will be beveled for welding, the blowpipe holder is adjusted to hold the head of the blowpipe at an angle to the wall of the pipe.

MECHANICAL ENGINEERING

A Monthly Journal Containing a Review of Progress and attainments in Mechanical Engineering and Related Fields, The Engineering Index (of current engineering literature), together with a Summary of the Activities, Papers and Proceedings of

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Progress of the Automotive Industry

DURING January and February motor shows are the rule in all our large cities and the automotive industry is on parade. Statistics of this industry for the past year are staggering. Production came nearly to the four million mark, about ten per cent of which were motor trucks. The number of automobiles registered in America is approaching 13,000,000, or one car to approximately eight people.

The industry in its present state is a tribute to the men who have developed the automobile from a wheezy, jolty, slow-speed carriage to the comparatively simple, smooth-running, comfortable vehicle which a child of ten can operate easily, if not always safely.

The past year has been one of severe competition and as a result there have been no outstanding changes in design, with the exception of the four-wheel brake and the balloon tire. Many changes in minor details that add greatly to comfort and safety have not materially affected the general appearance of the American automobile. In the future the tendency toward lighter construction will very probably be the principal fundamental development. At recent shows no recent designs of air-cooled cars were in evidence.

While the petroleum supply was for years looked upon as critical, the phenomenal overproduction during the past year has temporarily relieved the public mind. The fuel supply will undoubtedly have considerable effect on design changes in the automobile.

During the time the New York Automobile Show was held, Charles M. Schwab said that in a growing country like ours the potential demand for automobiles is beyond limit. There can be no such thing as a saturation point. He pointed out that the industry had passed through the experimental period and had attained a degree of standardization. Manufacturing costs have been reduced to a remarkably low figure. The chief problem, therefore, is the reduction of distribution costs, and he pleaded for earnest coöperative efforts on the part of every factor in the industry to achieve this end.

On the other hand, some months ago Mr. Alvan Macauley, President of the Packard Motor Car Co., pointed out that if there is a saturation point as regards automobiles, it lies not in limitations of purchasing power of the country—which has not yet been reached by any means—but in the physical limitations of our cities. In the big cities like New York and Philadelphia, driving has already become so difficult and traffic congestion has reached such a point that, not only do many automobile owners find the use of their cars less and less attractive, but state and municipal authorities are seriously beginning to consider the adoption of legislative means for limiting the number of cars on the highways.

There is another subject with which the automobile industry, among other agencies, will have to deal in earnest in the near future, and that is the rapidly growing number of traffic accidents. The number of persons killed and maimed by passenger cars and trucks, especially children, is already running into many thousands every year and it shows no signs of abatement. Notwithstanding the fact that statistically one person in eight in the United States owns an automobile, there is a growing indignation at these accidents and a feeling that a goodly share of them are unnecessary and preventable. That the public itself realizes that greater means of preventing accidents are needed is shown by the phenomenal success of the four-wheel brake in the last twelve months. There is every indication that unless from inside of the industry and the motor-owning community some means are taken to reduce traffic accidents to a reasonable amount, drastic legislation will be adopted which may materially affect the volume of sales and use of automobiles.

In the meantime it is well to bear in mind that the automotive industries in 1923 took more than 10 per cent of the country's total output of steel, and were exceeded in this respect only by two such basic and old-established industries as railroads and buildings.

It is not easy to sense accurately the economic effect of the automotive industry. The automobile today is regarded as a necessity and its effect on the habits and life of the people has been tremendous. Fluctuations in price and variations in rate of production in this industry react upon practically all other business elements in the country.

The Function of the A.A.A.S.

THE function of the engineer may be conceived as that of using the work of the pure scientist for the economic and social well-being of industry and the people. Engineers are in constant touch with the economic phases of their work, but the need for contact with the worker in pure science has not been fully appreciated. The American Association for the Advancement of Science furnishes this contact and provides a special engineering organization in which many engineering bodies coöperate. The Cincinnati meeting of this organization, reported in another column, furnished a deal of inspiration to those engineers who were able on that occasion to rub shoulders and exchange experiences with men in all branches of pure science. Engineers have much to gain in contacts of this sort, and in future gatherings of the A.A.A.S. the engineering profession should be represented to an even larger degree.

Science in Materials Handling

ONE of the attributes of modern civilization which differentiates it from savagery is its entire dependence upon transportation. However, it is only in recent years that one phase of transportation, that in industry, has received the engineering attention that its importance merits. The development of high-rate-production industries has emphasized these problems, and factories today are being built with a system for handling materials as an integral part of the structure. The development of the science of selecting such equipment has been along empirical lines, and it is only very recently that an attempt has been made to collect fundamental information as the basis for an enunciation of the principles of the design and selection of materials-handling equipment.

At the Montreal Spring Meeting the Materials Handling Division presented a formula for computing the economies of various installations of labor-saving equipment on a comparable basis. The formula takes into consideration proper allowances for interest, insurance, taxes, upkeep, depreciation and obsolescence, the yearly cost of power supplies, etc., and the saving in direct labor and in fixed charges in conveying equipment, and gives the relation between these factors and the yearly profit yielded by various types of mechanical equipment over manual handling.

This formula has attracted the attention of production men and materials-handling engineers. Its use should result in the contribution of facts which, after many such data have been collected, will increase materially the knowledge of the art and give it a scientific basis.

The formula is a simple measuring device obviously necessary for standardizing procedure, and is but a first step in the work of the Materials Handling Division.

The Peace Award

IN HIS presidential address at the last Annual Meeting, John Lyle Harrington pointed out the public obligations of the engineering profession. He emphasized the importance of the profession's dealing with politics through its individual members and through the coöperative efforts of its organizations. He called upon the engineer to give of his time and special knowledge in the public interest. The profession must not wait to be invited into the councils of nations but must make its opportunities and its place.

The recent publication of the American Peace Award and the popular referendum on it may afford one of these opportunities for the engineers of the country to give of their efforts in the solution of a great public question. The daily press of the country and the many trade and business organizations furnish the channels through which the opinion of our citizens may be registered.

The American Association for the Advancement of Science will conduct a referendum among its 11,348 members in the belief that this is a proper activity for a scientific organization, since the "advancement of science is dependent upon the free intercourse of all nations."

Federal Power Commission

THE following extracts from the report of the Secretary of the Federal Power Commission emphasize the importance and scope of water-power development in the United States.

Applications involving an estimated installation of 21,500,000 hp., permits and licenses issued for an aggregate installation of 7,500,000 hp., power, and 2,400,000 hp. built or building under license of the Commission, is the record of three years' administration of the Federal water-power act. When it is realized that only 1,400,000 hp. had been constructed under Federal authorization in the years preceding the passage of the Act, and that at the time of its passage the aggregate installation in all water-power plants in the United States amounted to only 9,000,000 hp., the satisfactory character of the legislation and the substantial results accomplished in its administration are apparent.

In creating the Federal Power Commission Congress did not create an independent establishment in the sense of one independent of the heads of the Executive departments, but a joint agency of three departments, charged with the duty of coördinating certain common activities. By harmonizing the collateral interests of the departments and by utilizing existing personnel to better advantage, the Commission has been able to accomplish many times more work than has ever been done before, and to serve as one of the best existing examples of Government coördination.

Superpower merely means the general employment of the best of present-day practice. It means that existing generating stations shall be electrically interconnected to a greater degree than now prevails, and that, whether as additions to existing facilities or as substitutes for what has become obsolete or inadequate, new stations when built shall be of large size and high efficiency. It does not mean any general scrapping of existing facilities, or any huge program of trunk-line transmission construction, but the gradual expansion of existing systems under such conditions that when they meet they may be interconnected and operated as a single system.

Superpower is not something for the future. It is with us now and has been for several years. Only four gaps with a total of about twenty-five miles require to be closed in order to have an interconnected system along the Pacific Coast reaching from British Columbia to Mexico, a distance of some 1400 miles. In the South Atlantic States interconnection has been effected through Alabama, Georgia, North and South Carolina and Tennessee, with extensions projected into Kentucky, the Virginias, and Ohio. Both of these systems have hundreds of thousands of horsepower of generating capacity and have an annual energy output measured in billions of kilowatt-hours. The current popularity of the term "superpower" has arisen from the efforts being made to secure the adoption of a similar program in the Northeastern States where, on account of the location of the major sources of fuel and of water power, and on account of the extent and density of power demand, such a program would seem peculiarly desirable.

Since the interconnection of hydro plants upon streams of different flow characteristics, and of hydro plants with steam plants, permits a far greater utilization of the water supply than would otherwise be possible, interconnected systems afford the conditions under which water powers can be most efficiently operated. The initial cost of a hydroelectric plant with its dams, reservoirs, canals, power houses, and transmission lines is likely to exceed considerably the cost of a steam plant of like capacity. Its operating expenses are, however, lower and it burns no fuel. It becomes economically superior to the steam plant whenever its lower operating costs more than offset its greater interest charges. Its interest charges are fixed and its total operating expenses vary but slightly whether the plant operates at partial or at full load, so that, with total expenses practically a fixed item in any particular hydro plant, the cost per kilowatt-hour decreases as the output increases. When seasonal storage and adequate pondage are available the hydro plant can be operated on base load or on daily or seasonal peak load as best suits general operating conditions in the system, a situation which not only permits the most complete use of the available water supply, but also affords operating flexibility and economy in the system as a whole. The close relation between superpower systems and water-power development, and the extent to which they are interdependent may be indicated by the fact that our two greatest systems, the one on the Pacific Coast and the other in the South Atlantic States, have been developed concurrently with the development of water powers, and that there are no systems based upon steam power comparable with these two in extent of territory served. Water powers will be essential factors in the creation and expansion of superpower systems not only in the West and in the South where water power is the dominant source of electric energy, but also in the north and east where on account of lesser water-power resources, dependence must continue to be placed upon steam power for the production of a large part of the energy supply. It is only a matter of time when through the natural expansion of adjacent local groups of plants and lines we should have in the East a superpower system rivaling that of the Pacific Coast.

Cincinnati Meeting of the A.A.A.S.

THE seventy-fifth anniversary of the American Association for the Advancement of Science was celebrated at its Cincinnati meeting held December 27, 1923 to January 2, 1924. The programs of the various sections were planned to develop the history of science during the past three-quarters of a century. Over twenty-five hundred scientists attended the meeting.

Dr. Willis Rodney Whitney, Director of the Research Laboratory of the General Electric Company, presented the scientific lecture on Friday evening, December 28, in the Hughes High School auditorium. Dr. Whitney spoke on The Vacuum, There is Something in It, and his address was illustrated by striking experimental demonstrations of the latest developments in vacuum tubes.

The Engineering Section of the A.A.A.S. held two sessions, both of which were presided over by Prof. John T. Faig, Chairman of the Section. The retiring Chairman, F. M. Feiker, Vice-President of the Society for Electrical Development, opened the meeting with an address entitled New Tasks for the Sons of Martha, in which he pointed out some of the activities of engineers in public life and emphasized future opportunities. He was followed by John Mills, Personnel Director of the Western Electric Company, who described The Atom of the Electronic Physicist. Charles F. Kettering, President of the General Motors Research Corporation, outlined Some Future Problems of Engineering in his usual entertaining way. He segregated engineering activity into three phases which he classed as pure science, scientific engineering, and commercial engineering. He also pointed out that there is one kind of engineering which is merely mechanical stenography. To do engineering work properly the engineer must have a cost accountant on one side and a pure scientist on the other, and his effectiveness is measured by his service to human welfare. Engineering is at the basis of all economics in that its function is to save time and to improve the utility of materials and men.

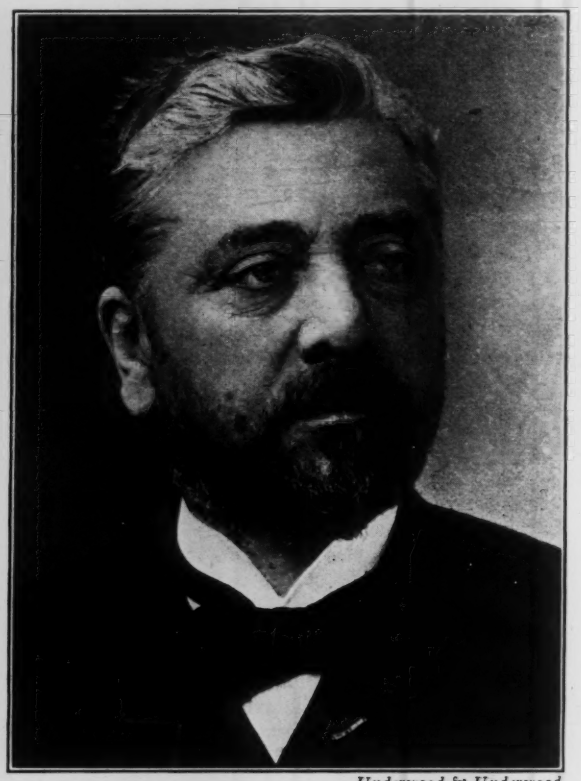
Ernest L. Robinson, of the turbine department of the General Electric Company, presented a paper dealing with some of the Recent Developments in Heat Engineering, in which he discussed ideal conditions for transforming heat energy, the extraction cycle, the binary-vapor turbine, the advantages of superheat, and the effect of air preheating. The closing paper was by Sanford A. Moss, of the research department of the General Electric Company, who told of the future of the gas turbine. He sketched the work done in utilizing combustion gases in a turbine and showed the practical development of this device in the supercharger which made airplane flights at high altitudes possible.

The Engineering Section of the A.A.A.S. has affiliated with it the A.S.C.E., the A.I.M.E., the A.S.M.E., the A.I.E.E., the A.S.T.M., and the Illuminating Engineering Society. At the close of the meeting the Section Committee, made up of representatives of these organizations, reëlected Professor Faig as Chairman of the Section for the ensuing year.

Alexandre Gustave Eiffel

ALEXANDRE GUSTAVE EIFFEL, engineer and scientist, builder of the famous Tower which bears his name and author of scientific treatises of inestimable value, died on December 28, 1923.

M. Eiffel was born at Dijon, France, on December 15, 1832. After his graduation from the Ecole Centrale des Arts et Manufactures in 1855, he became interested in the study of construction in steel. At the age of twenty-six he was intrusted with the construction of a steel bridge at Bordeaux. In the foundation of this bridge he was one of the first to make use of compressed air. A little later he applied an improved system of sinking hollow piles with compressed air and the aid of a hydraulic press.



Underwood & Underwood

ALEXANDRE GUSTAVE EIFFEL

In 1867 Eiffel founded an establishment for iron and steel construction which was operated under his direction until 1890. In assembling his structures he introduced many noteworthy improved methods, through which he succeeded in placing with boldness and precision trusses and bridges of lengths which were then quite exceptional. He improved the placing of straight bridges by devising a tipping frame and applying it to spans where this method was thought impracticable. He invented and made popular demountable and portable bridges for military and colonial use.

Among Eiffel's great works may be mentioned the viaduct of the Oise, the railway bridge over the Tarde, the railway and carriage bridges over the Tagus and at Vianna in Portugal, a number of bridges in Cochin-China, the great arched bridge at Szegedin in Hungary, the bridge at Oporto over the Douro, and the bridge of Garabit, one of the most remarkable works of the kind in France and probably Eiffel's most important work. Among other constructions he has to his credit are numerous steel-frame buildings, including churches, railway stations, and public buildings. For the dome of the equatorial telescope of the Observatory at Nice, Eiffel was awarded the Monthyon Prize in Mechanics by the Académie des Sciences.

In 1887 the Panama Canal Company intrusted to Eiffel the general plan for a system of locks. He performed this task in a way which should have assured the accomplishment of the great enterprise, but the work was stopped by the unfortunate bankruptcy of the company. In the investigation which followed M. Eiffel was fully exonerated from complicity in any of the corrupt transactions which wrecked the enterprise. The injustice of the attacks on him was demonstrated by the Court of Cassation from the judicial point of view and by the Council of the Legion of Honor from the moral point of view.

Eiffel's best-known work is the Eiffel Tower which was constructed as one of the features of the Paris World's Fair in 1889. The Tower is 984 feet above the ground, contains 7000 tons of iron in its construction, commands a view of 85 miles, and houses a fine meteorological observatory with physical and biological laboratories. The Tower was constructed at a cost of more than a million dollars for which the French government voted only $292,000. Eiffel himself supplied the remaining three-quarters of a million dollars, for which he was granted the receipts from admission fees for a period of twenty years. The receipts for 1889 alone all but reimbursed him.

Since 1890 M. Eiffel has devoted himself entirely to scientific research, using the Tower observatory and laboratories for the purpose. He has published numerous scientific works on meteorology. He has made studies of the problems of wind pressure and currents and has contributed in large measure to the progress in aviation through his experiments and researches in aerodynamics. His great work, Resistance of the Air, published in 1913, was immediately translated into English and is one of the most important contributions ever made to this problem.

M. Eiffel was elected an Honorary Member of The American Society of Mechanical Engineers in 1889. He is a Past-President of the Société des Ingénieurs Civils de France and an honorary member of most of the great scientific societies of Europe and America. He was a laureate of the French Institute, an officer of the Legion of Honor, a Knight of the Iron Crown of Austria, and a Commander of the Order of the Conception of Portugal, of the Crown of Italy, of Isabella of Spain, and of St. Anne of Russia.

London—An Engineering Mecca

LONDON will be the Mecca of the engineering world next summer. The Empire Mining and Metallurgical Congress, June 3–6, and the World Power Conference, June 30–July 12, are preparing programs and making plans that will attract a representative international engineering audience. With sub-committees in all the leading countries of the world, those in charge of the arrangements for the Power Conference are developing a comprehensive program in which many of the most prominent international authorities have consented to participate.

As would be expected, engineers from the United States, where there is an extraordinary development of power of all kinds, will have a prominent part in the technical program of the Conference. Among those who have already consented to prepare papers are Samuel Insull, John R. Freeman, W. M. White, H. B. Taylor, D. S. Jacobus, F. G. Baum, W. S. Murray, Charles T. Main, Owen D. Young, O. C. Merrill, A. P. Davis, Peter Junkersfeld, George A. Orrok, and J. W. Lieb.

A few of the events which it is understood have been tentatively planned for closing days of the Conference and immediately following it, are: Conversazione by the Joint Societies in Albert Hall; Kelvin Centenary Oration (probably by J. J. Thompson); Kelvin Centenary Reception and Banquet (probably with Lord Balfour in the chair); reception at Cambridge University; special services in Westminister Abbey and St. Paul's Cathedral; visits to Kenilworth Castle, Stratford-on-Avon, and Birmingham; and visits to the underground railways and to Windsor Castle.

As stated before, these events are only tentatively planned and will necessarily be limited to some extent, but following them it is expected that there will be tours in Great Britain, France, Switzerland, Italy, Scandinavia, and Lapland. These tours will probably be under the supervision of World Power Conference committees of each country.

Fred R. Low, President of The American Society of Mechanical Engineers, is chairman of the Transportation Committee in the United States. Members who desire to attend should notify him if they wish to be supplied with particulars regarding transportation.

Engineering and Industrial Standardization

Standard Sizes for Shafting Key Stock

DURING the December, 1923, Annual Meeting of The American Society of Mechanical Engineers the Sectional Committee on the Standardization of Shafting, Cloyd M. Chapman, Chairman, held a meeting at which the letter-ballot on the Standard Sizes for Shafting Key Stock was reviewed and a final vote taken. This standard includes (1) two series of nominal sizes for plain keys, square and flat, for shafts varying in diameter from 7/16 in. to 6 in. and, (2) tolerances on key-stock sizes.

The American Society of Mechanical Engineers is Sponsor for this Sectional Committee, so this report is now before this body for final approval and adoption, after which it will be transmitted to the American Engineering Standards Committee for approval as a Tentative American Standard. The proposed standards are given in Table 1 for the information of the readers of MECHANICAL ENGINEERING and also to enable them to criticize and comment on this proposal to the Sponsor Body. All communications should be addressed to C. B. LePage, Assistant Secretary, The American Society of Mechanical Engineers, 29 West 39th Street, New York.

TABLE 1 STANDARD SIZES FOR SHAFTING KEY STOCK

Shaft Diameters (Inches) To and Over including	Key Nominal Sizes (Inches) Square Keys W × T	Flat Keys W × T	Key-Stock Sizes (Inches) Square, Minimum Width S	Square and Flat, Minimum Thickness S	F	Tolerances	Square, Maximum Width S	Square and Flat, Maximum Thickness S	F
7/16 – 11/16	1/8	1/8 × 3/32	0.123	0.123	0.092	−0.0020	0.125	0.125	0.094
11/16 – 7/8	3/16	3/16 × 3/32	0.185	0.185	0.154	−0.0020	0.1875	0.1875	0.156
7/8 – 1 3/16	1/4	1/4 × 3/16	0.248	0.248	0.185	−0.0020	0.250	0.250	0.1875
1 3/16 – 1 3/8	5/16	5/16 × 3/16	0.310	0.310	0.185	−0.0020	0.3125	0.3125	0.1875
1 3/8 – 1 11/16	3/8	3/8 × 1/4	0.373	0.373	0.248	−0.0020	0.375	0.375	0.250
1 11/16 – 1 7/8	7/16	7/16 × 5/16	0.435	0.435	0.310	−0.0025	0.4375	0.4375	0.3125
1 7/8 – 2 1/4	1/2	1/2 × 3/8	0.497	0.497	0.373	−0.0025	0.500	0.500	0.375
2 1/4 – 2 3/4	5/8	5/8 × 7/16	0.622	0.622	0.435	−0.0025	0.625	0.625	0.4375
2 3/4 – 3 1/4	3/4	3/4 × 1/2	0.747	0.747	0.497	−0.0025	0.750	0.750	0.500
3 1/4 – 3 3/4	7/8	7/8 × 7/8	0.872	0.872	0.622	−0.0030	0.875	0.875	0.625
3 3/4 – 4 1/2	1	1 × 3/4	0.997	0.997	0.747	−0.0030	1.000	1.000	0.750
4 1/2 – 5 1/2	1 1/4	1 1/4 × 7/8	1.247	1.247	0.872	−0.0030	1.250	1.250	0.875
5 1/2 – 6	1 1/2	1 1/2 × 1	1.497	1.497	0.997	−0.0030	1.500	1.500	1.000

Standard Sizes of Brass Crucibles Submitted for Approval by A.E.S.C.

THE Plumbago Crucible Association has submitted its Standard Sizes of Brass Crucibles for approval by the American Engineering Standards Committee. These standard sizes were developed originally by a committee consisting of representatives of users and manufacturers of crucibles. The work was begun in 1913 under the auspices of the American Institute of Metals. In 1915 the committee completed its task by the selection of certain sizes then made and recommended these for adoption as standards. In 1919, at the instance of the American Institute of Metals, a vote was taken on the formal approval of these sizes as standards, but they were never put into actual use on account of disagreement regarding the selection of the sizes on a purely arbitrary basis.

As a result of this disagreement, one of the members of the Plumbago Crucible Association was employed to work out a logical and comprehensive set of standard sizes. The shape which had become established through long usage was adopted as a basis and a series of sizes was developed in which every size of crucible bears a simple relation to every other size. Moreover the capacity of all can be computed by the same formula. In working out this series certain adjustments were made in order to avoid confusion with existing sizes and to permit specifying, as nearly as possible, the same size number in the new line of crucibles as had been used, on the average, for the old unstandardized sizes. All but two crucible manufacturers, who make crucibles for brass-foundry use, have made molds to conform to the new sizes. Under this system the product of every crucible manufacturer will have the same outside shape, so that wherever they are used, the tongs and bails will fit.

Comments on these standards are solicited by the A.E.S.C. and should be addressed to Dr. P. G. Agnew, Secretary, 29 West 39th Street, New York, N. Y.

A.E.S.C. Will Call Conference on Cast-Iron Pipe

AT A recent meeting of a special committee of the American Engineering Standards Committee called for the purpose of considering the adoption of certain standards for cast-iron pipe, it was voted that the special committee recommend to the A.E.S.C. the calling of a representative conference on the standardization of bell-and-spigot and flanged cast-iron pipe and fittings, to consider the advisability of developing specifications covering dimensions and materials. This action resulted from a review of two sets of specifications for cast-iron pipe submitted for the approval of the A.E.S.C., one set by the American Gas Association and the other by the American Society for Testing Materials.

When the special committee examined into the advisability of giving to any of these specifications the status of American Standard, it was found that none of them seemed to satisfy completely the needs of all interests concerned in the manufacture and use of this equipment. The history of the standardization of pipe flanges and flanged fittings for pressures from 50 to 3200 lb., under the sponsorship of The American Society of Mechanical Engineers, The Committee of Manufacturers on Standardization of Fittings and Valves, and The Heating and Piping Contractors National Association, was also reviewed. After a thorough discussion of all phases of the situation, the vote was taken to defer approval of the cast-iron pipe standards presented for approval pending consideration of the entire subject by a conference fully representative of those having an interest in the project.

As a result of the committee's recommendation, the Chairman of the A.E.S.C. was authorized at a meeting of the Main Committee on October 11 to call the conference as recommended. It was understood that the conference would consider to some extent soil pipe and other light types of cast-iron pipe, with respect to possible standardization.

The special committee which considered the specifications submitted for approval and recommended the action taken above was broadly representative of all groups interested in the subject, and included the following individuals.

S. G. FLAGG, JR., *Chairman*, member A.E.S.C., American Society of Mechanical Engineers
F. A. BARBOUR, representing American Water Works Association
E. A. BARRIER, member A.E.S.C., Fire Protection Group
A. W. CLAUSSEN, representing Underwriters' Laboratories
W. FORSTALL, representing American Gas Association
A. H. HALL, member A.E.S.C., Gas Group, and representing American Gas Association
W. G. HAMMERSTROM, chief engineer, Lynchburg Foundry Company
H. KELLY, representing Associated General Contractors of America
F. A. MCINNES, representing New England Water Works Association
J. C. MELOON, representing National Automatic Sprinkler Association
N. F. S. RUSSELL, representing U. S. Cast Iron Pipe and Foundry Company
F. F. SCHAUER, representing Natural Gas Association of America
R. TOENSFELT, representing American Society for Municipal Improvements
W. WOOD, president R. D. Wood & Company
C. D. YOUNG, *Chairman* of the meeting, member A.E.S.C., American Society for Testing Materials.

At the meeting of October 4, other representatives as follows were in attendance:

C. B. LEPAGE, assistant secretary of The American Society of Mechanical Engineers
C. W. MOWRY, of the Associated Factory Mutual Fire Insurance Companies
T. H. WIGGINS, of the American Water Works Association
C. L. WARWICK, secretary-treasurer of the American Society for Testing Materials
JOHN WOODCOCK, of the National Automatic Sprinkler Association
R. DEWEES, of Stanley G. Flagg & Company.

The date, time, and place of this Conference will be announced as soon as they are set by the American Engineering Standards Committee.

Economic Phases of Coal Storage

(*Continued from page 76*)

his neighbors. He can then stay out of the market while his neighbor is in distress and is bidding up the price to scarcity levels. If he stores less than his neighbor he will have to enter the market first, and will be there when the price reaches the top. The wise course for a consumer during a large suspension is to keep on buying as long as he can get coal at a moderate price. The time to utilize the stock pile is not in the first stages of the suspension but in the last stages, or even for months after work has been resumed. Practically all these great suspensions have ended in distress among consumers, rapid increase in price, pressure on the union operator to settle up and take care of his customers, and, still more powerful, in the operators' desire to participate in the highly profitable market that follows a strike. Why be one of the consumers whose distress forces a settlement? Would it not be better business, if the consumer is to store at all, to store enough to carry him past the peak of the price?

If these periodic crises in coal supply are to continue, there can be little doubt that a consumer will save by storing unless his connections are such that he is certain of a steady supply even in the event of a great strike. Few consumers, however, are in this happy position of guaranteed supply.

The buyer of coal naturally raises the question whether these crises will recur or not. There is no positive answer. He must take a chance. All that can be said is that there appears in the present situation no new factor to prevent from time to time those very suspensions that occurred in the even years before the war and that have recurred in intensified form ever since. The labor question in the coal industry is not settled. The causes of instability have not been removed.

There is already talk of a bituminous strike next April, when the present wage agreements expire, but to attempt to prophesy would be out of place here. If there is no strike it will have been in part prevented by consumers who have taken the precaution to store; and if this general preparedness helps the operators and the miners to reach an agreement peaceably the expenditure has been worth while. The holder of a fire-insurance policy need not regret that he has no fire.

Discussion on Calorimetric Method of Surveying Behavior of Steam

(*Continued from page 90*)

The first impression one gains from going through such a workout is the great simplicity and convenience of the method of the paper; but when we consider the possible cumulative effect of experimental errors upon a differential result the prospect is not so pleasing. It appears that direct results by the difference method ought to be checked by internal-energy computations upon the individual experiments. For this purpose calorimeter volume need be known with but moderate precision, since it affects only the small vapor quantity, while M_a and M_b must be precisely determined in any case. For the computation of vapor energy the steam formulations already in existence are plenty near enough to absolute correctness.

As to the whole scheme the following remarks may be made:

For heat of liquid it seems to offer much better possibilities than the quartz "cartridge" method of Dieterici.

For heat of vaporization it follows the essential lines of other experiments, requiring difficult measurements of heat added and of mass, with uncertainty, first as to the attainment, then as to the real existence, of an exact state of dry saturation.

In regard to volume, if latent heat L is accurately determined our knowledge of the Clapeyron ratio from other sources will lead at once to vaporization volume $(u' - u)$ or v. The ratio of β to L will then give liquid volume u. Obviously, from the relative size of the quantities to be observed, this ratio (as an experimental quantity) can be used in but one direction. It positively could not be applied to a measured liquid volume in order to get steam volume.

This scheme can certainly give good and useful results if the difficulties of high-pressure work can be handled. It is results at from 300 to 1500 lb. pressure that we want.

Progress in Steam Research—On the Joule-Thompson Effect

(*Continued from page 87*)

pressure being about 570 lb. abs. An interesting feature of the new determination is that we have actually reached and passed experimentally the well-known maximum in the $H_{sat.}$ curve.

As said at the beginning, this work has been presented chiefly in the hope that every one who is interested in steam tables at all will be good enough to put some time into analyzing the relationships between this work and his own data or his own formulation, or anything that he believes to be true about steam, and that he will communicate the results of that comparison to us at Harvard, so that we may profit by it, either through more careful rechecking in doubtful places or by cleverer handling of the data.

It is hoped that the material in Figs. 10 to 13 is in such shape as to facilitate checks and comparisons by others working in this field, and that we may therefore hope to receive valuable criticisms and suggestions.

FOLLOWING the presentation of Dr. Davis' report, Geo. A. Orrok, chairman of the Executive Committee of the Steam Table Fund expressed his exceeding gratification at the progress which had been reported by the investigators. Of the temperature measurements made by the three investigators, he believed that it could be said that they equaled any that had been made in the world in the point of accuracy. He wanted particularly to remark not only on the fine mechanical work which Dr. Keyes had done in the making of his apparatus, much of it with his own hands, but on that done at the Bureau of Standards.

Mr. Orrok expressed the wish that every one interested in the present steam-table work would visit the Bureau of Standards, the Massachusetts Institute of Technology, and the Jefferson Laboratory at Harvard, and witness its progress, noting the extreme care which is being taken so that everything shall be up to the last minute in accuracy. The patience with which these investigators were working, as well as the long hours that they were putting into the work, he said, was most commendable. There was a great clamor nowadays for an eight-hour day, and a recent investigation had shown that a twelve-hour day was entirely unnecessary; but the engineer and the investigator worked ten, twelve, and sixteen hours, and sometimes twenty-four hours a day, and did not clamor for a shorter day but for more work to do!

As to the time required to complete the investigation, he would say that the Bureau of Standards was getting its apparatus ready and would shortly attack one of the most difficult parts of the problem. They were about to determine the specific heat of water from 32 to 212 deg., and as much higher as possible, but they would have to determine the specific heat of water from 32 to 212 deg. and the value of the mean B.t.u., before it would be possible to commence the calculation of the final steam table that was in mind. This determination had to be made with an accuracy of possibly one part in three or four thousand, for an accuracy of one part in 300, which was what was being used now, was not good enough for the purpose, and it was particularly for this reason that the Bureau of Standards had been chosen to carry out this portion of the investigation.

The work of Dr. Keyes and also that of the Bureau of Standards thus far had largely consisted in getting the apparatus ready and finding out their constants. After that had been done, the actual work of making the experiments would probably not take a very long time. It might be possible to report some real results next December, which would be the end of the three-year period during which the work had been carried on. He hoped that a reasonably good steam table would be ready in four years; and an accurate one in five years.

Library Notes and Book Reviews

From Immigrant to Inventor

FROM IMMIGRANT TO INVENTOR. By Michael Pupin, Professor of Electro-Mechanics, Columbia University. Charles Scribner's Sons, New York, 1923. Cloth, 6 × 9 in., 396 pp., illus., $4.

A FASCINATING story for scientist and lay reader alike is the life of Michael Pupin, the inventor of an inductance coil, known all over the world as the Pupin coil, used in long-distance telephony. We are living just now in an age of biography; and as long as biography can be the brilliant and gripping story of adventure that it is in From Immigrant to Inventor, there will be less and less need for fiction. Dr. Pupin writes in an easy narrative style. He has an unusual story to tell of a little Serbian herder of cattle who ran away from home to the land of Franklin and Lincoln, a lad who adventured far and achieved greatly. His story has a tremendous human appeal.

There have been few great scientists who have combined with their scientific achievements the ability to present in their writings the human qualities which make for universal appeal; but Dr. Pupin has accomplished admirably this difficult feat. He makes science not a collection of hard, cold facts, but a living vital part of all life. He first caught the spirit of science as a boy from the religion of his mother, which bade him always seek eternal truth. In his search for truth he is able to catch and hold the spirit of her religion. To him science is Divine Philosophy, the abstract side of poetry, and like the true philosopher or poet, the matter of answering the question, What Is Light? never excludes the attempt to learn the answer to that other important question, What Is Life?

Dr. Pupin states that the main object of his narrative is to describe the rise of idealism in American science. From the vantage point of his Serbian inheritance, he is permitted to speak of the idealism instead of the materialism of American science in a way that might be considered too boastful if he were a native born. It is a glowing record of science in America for the past fifty years, and even such subjects as the electromagnetic theory of matter are expounded so that the charm and humanness of the author are never lost.

But more than half of the book is taken up with Pupin's story of himself, his native Serbia and his early experiences in the United States. It is the story of an immigrant boy with a steadfast loyalty to the best traditions of his native village Idvor, but who recognized that there are also American traditions, and that the opportunities in America are inaccessible to the immigrant who does not recognize their meaning and vital importance in our national life. Pupin was fortunate, perhaps, in never having many of the unpleasant experiences that often befall the immigrant; or possibly he was able to avoid them because he had a fighting instinct that won respect for him whenever it was required that the language of fists be spoken. He brought both brains and brawn to this country, and by an unstinted use of both he rose to eminence as a scientist and inventor. Now he has given us a book that makes science intelligible and scientists human to the layman, and which should do much to build the bridge of reasonable international relationships through the elimination of some foolish racial antipathies.

BILDTELEGRAPHIE. By Arthur Korn. Walter de Gruyter & Co., Berlin and Leipzig, 1923. Boards, 4 × 6 in., 146 pp., illus., diagrams, $0.25.

A brief survey of the most important methods and apparatus for transmitting handwriting, drawings and photographs by telegraphy. A historical introduction reviews the early investigations, reaching back over fifty years. The principles of telegraphic copying and of writing at a distance are then explained and the methods for transmitting photographs are set forth. While the book gives special attention to Dr. Korn's own methods, those of other investigators are not neglected. The final chapter discusses television.

BOILER CHEMISTRY AND FEED WATER SUPPLIES. By J. H. Paul. Second edition. Longmans, Green & Co., London and New York, 1923. Cloth, 6 × 9 in., 252 pp., diagrams, tables, $4.50.

Discusses boiler waters, scales and deposits, softening, carbonic acid and its action on iron, corrosion, condensed waters, priming, and other topics of importance. Considers especially the chemical reactions that take place in high-pressure boilers, and their effect upon the steaming capacity of the boiler and upon the boiler itself. The new edition has been revised.

DESIGN OF DIAGRAMS FOR ENGINEERING FORMULAS AND THE THEORY OF NOMOGRAPHY. By Laurence I. Hewes and Herbert L. Seward. McGraw-Hill Book Co., New York, 1923. Cloth, 9 × 12 in., 111 pp., diagrams, $5.

The usefulness of a diagrammatic solution of a formula is being increasingly recognized, and in this volume the authors have attempted to present in a practical way the principles of the design of diagrams or nomograms for the solution of engineering and other formulas. As the usefulness of diagrammatic solutions is in proportion to the resistance of the formula to calculation, the book does not merely give elementary methods of drawing simple diagrams but also aims to develop the grasp of the reader so that he will be able to analyze the more complex formulas of engineering. Fifty-four illustrative examples are given, which include many charts of general usefulness to engineers.

DIRECT-ACTING STEAM PUMP. By Frank F. Nickel. Second edition. McGraw-Hill Book Co., New York, 1923. Cloth, 6 × 9 in., 258 pp., illus., diagrams, tables, $3.

The development of this pump, the types in use, the detail of the steam and water ends, the factors that affect its performance, its suitability for various purposes, and its operation are considered. A number of changes have been introduced in this edition.

ELASTICITY AND STRENGTH OF MATERIALS USED IN ENGINEERING CONSTRUCTION; Section 3, Theory of Torsion in Shafting and Double Bending Plates. By C. A. P. Turner. The author, Minneapolis, Minn., 1923. Cloth, 6 × 9 in., 122 pp., diagrams, $5.

This section of Mr. Turner's treatise is devoted to the analysis of round shafts; the torsional analysis of square, rectangular, triangular and oval prisms; the analysis of combined bending and twisting resistance in homogeneous flat plates; the analysis of composite plates and the theory of continuity with variable moment of inertia; and unbalanced moment in monolithic floors and columns.

The methods of graphic analysis given permit the planes of rupture in shafts to be located readily and disclose the cause of rupture. They also give a clear insight into the flexure of plates and show that an important element in their resistance, heretofore disregarded in mathematical analysis, is the squeeze or stretch of their neutral planes. The new method will, in the author's opinion, give a clearer conception of the relation of states of stress to deformation in such problems than that obtained from the involved equations of the mathematical theory of elastic solids, and so tend to eliminate fundamental errors in the rules of design in building-code laws.

ELECTRICITY AND ITS APPLICATION TO AUTOMOTIVE VEHICLES. By Paul M. Stone. D. Van Nostrand Co., New York, 1923, Cloth, 6 × 9 in., 844 pp., illus., diagrams, $4.

This book gives a systematic account of the electrical equipment of automobiles. Starting with the elementary principles of electricity, it takes up successfully primary cells, storage batteries, measuring instruments, battery ignition, magnetos, spark plugs, generators, electric motors, gear shifts and protective and controlling devices. Following this are chapters devoted to the details of the various systems used on American automobiles. Information is given on the location and removal of troubles and on methods of operation.

ELEMENTS OF STORAGE BATTERIES. By Cyril M. Jansky and Harry P. Wood. McGraw-Hill Book Co., New York, 1923. (Industrial education series.) Cloth, 6 × 9 in., 241 pp., illus., diagrams, tables, $2.50.

This book is intended to meet the need for simple, elementary exposition of the principles, operation, and maintenance of storage batteries, which has been created by the extensive use of these converters of energy and by the radical changes in practice during recent years. The authors have kept in mind the needs of the man without special training who uses or operates storage batteries and wishes to know something about the operation and repair of them.

ENGINEERING STANDARDS. By The Heating and Piping Contractors National Association. Cloth, loose leaf, 5½ × 8½ in., 49 pp., illus., diagrams, tables.

This is a loose-leaf volume containing a "Foreword" in which the method of arriving at the results is given and the formula for figuring radiation is fully explained. The data pages contain transmission factors for the various types of building construction, tables of temperature factors for outside temperatures ranging from −20 to +20 deg. fahr. and room temperatures ranging from + 40 to + 80 deg. fahr., an infiltration table covering the inleakage of the various types of doors and windows, a table of base temperatures and exposure factors for a number of important cities, and diagrams of radiator enclosures with the effect of each upon the efficiency of the radiator.

Engineering Standards have been developed by the associations committee on standardization to give to its members a complete, modern, and scientific method of figuring the quantities of radiation necessary in any class of building in any locality. In the original conception of this project it was designed for membership service only. The number of requests for copies from engineers, architects and other interested in the advancement of the heating industry showed that the Engineering Standards filled a real want and that the association could perform a real public service by making the book available to all who are interested.

ENGINE-ROOM PRACTICE. By John G. Liversidge. Eleventh edition. Charles Griffin & Co., London; J. B. Lippincott Co., Philadelphia, 1923. Cloth, 5 × 8 in., 429 pp., illus., diagrams, $6.

This textbook is intended for students and apprentices but should also be useful for reference to young engineers. It covers the care, maintenance, and repairing of the machinery of steamships, including the auxiliary electric and refrigerating machinery, and has chapters on the duties of engineers in the Royal Navy and leading steamship companies. The present edition has been enlarged by the addition of information on steam turbines and has been revised throughout.

DIE GASERZEUGER. By H. R. Trenkler. Julius Springer, Berlin, 1923. Boards, 6 × 9 in., 378 pp., illus., diagrams, tables, $3.50.

In spite of the previous writings on the gas producer, the author believes there is need for a new handbook, especially since the field for gas firing is always growing larger, and new designs of generators are always being introduced. The recovery of by-products has also recently become important. The book covers the fuels, the chemical and technical principles of gasification, producer types, design of producer plants, purification of gas and by-product recovery, and operating methods. Practice is described carefully and the subject is reviewed critically throughout. Patent references are given in an appendix.

HANDBOOK OF INDUSTRIAL OIL ENGINEERING. By John Rome Battle. Second edition. J. B. Lippincott Co., Philadelphia, 1923. Fabrikoid, 5 × 8 in., 1141 pp., illus., diagrams, tables, $10.

This new edition, following the first after but three years, has been thoroughly revised and brought up to date. It contains tables, technical data and general information on the industrial utilization of petroleum products for all purposes except for fuel, and also of the common fatty oils. The book covers a wide field and will prove useful to many classes of readers.

INDUSTRIAL COST ACCOUNTING FOR EXECUTIVES. By Paul M. Atkins. McGraw-Hill Book Co., New York, 1923. Cloth, 6 × 9 in., 322 pp., illus., $4.

This book is intended to show executives some of the possible uses of cost accounts and to show how these benefits may be obtained. For the latter purpose, a system for recording costs is shown. This describes methods for a manufacturing business of the production-order type, the discussion being confined to methods that have given satisfaction over a wide range of conditions. A bibliography is included.

LATHE-WORK. By Paul N. Hasluck. Eleventh edition. D. Van Nostrand Co., New York, 1923. Cloth, 5× 8 in., 232 pp., illus., $2.

A handy guide for beginners, treating the subject in a practical manner.

MACHINE DESIGN DRAWING ROOM PROBLEMS. By C. D. Albert. John Wiley & Sons, New York, Chapman & Hall, London, 1923. Cloth, 6 × 9 in., 320 pp., illus., diagrams, tables, $3.

This textbook is based on the author's experience in teaching design to engineering students at Cornell University. It purposes to offer complete material for a drawing-room course in general machine design and is based upon the belief that complete, comprehensive problems are superior to those dealing with unrelated details or groups of details.

MAKERS OF SCIENCE: Mathematics, Physics, Astronomy. By Ivor B. Hart. Oxford University Press, London, 1923. Cloth, 5 × 8 in., 320 pp., illus., portraits, $2.75.

This book is designed to give students of science an elementary account of the history of its development. The author has adopted the biographical method and presents his material through biographies of a series of individuals, from Aristotle to Kelvin, who have had an important influence on our knowledge of the sciences under consideration. These biographies are linked together, so that a connected history of some of the broader movements in scientific history is obtained.

MANUAL DE INSTALACION DE RUEDAS PELTON. By Gabriel Sanin Villa. Antonio J. Cano, Colombia, S. A., 1923. Paper, 6 × 9 in., 154 pp., tables.

A practical handbook on the selection and installation of Pelton wheels. Explains the calculations necessary, describes the accessories and contains the tables required by the engineer. The book, the work of a member of the American Institute of Mining and Metallurgical Engineers, was awarded a gold medal at the Exposicion Industrial de Medellin, 1923.

MATERIALS AND THEIR APPLICATION TO ENGINEERING DESIGN. By E. A. Allcut and E. Miller. Charles Griffin & Co., London; J. B. Lippincott Co., Philadelphia, 1923. Cloth, 6 × 9 in., 519 pp., illus., diagrams, tables, $12.50.

The present book is not intended to replace textbooks on the theory and general principles of applied mechanics, but to supplement them by providing the engineer with information which will assist him to select suitable materials for commercial use. The book discusses the testing and heat treatment of metals and alloys, gives many data on their properties, and shows how these materials are used by typical examples. Some attention is paid to non-metals. The subject is treated on economic and practical lines. The figures, curves, and other data are taken from commercial supplies, not from samples made of comparatively pure metals under laboratory conditions. The authors write from the point of view of the engineer rather than the metallurgist.

MECHANICAL APPLIANCES, MECHANICAL MOVEMENTS AND NOVELTIES OF CONSTRUCTION. By Gardner D. Hiscox. Fifth edition. Norman W. Henley Publishing Co., New York, 1923. Cloth, 6 × 9 in., 412 pp., illus., $4.

This book contains nearly a thousand mechanical appliances for the generation, transmission, and measurement of power, for gearing machinery and for various industrial purposes. Describes many attempts to obtain perpetual motion. The descriptions are brief and are accompanied by sketches. This edition is largely a reprint of edition four, with an added section on radio telephony and telegraphy.

MECHANICS OF THE GASOLINE ENGINE. By H. A. Huebotter. McGraw-Hill Book Co., New York, 1923. Cloth, 6 × 9 in., 313 pp., illus., diagrams, tables, $4.

This work, which is intended especially for the convenience of

the designer, aims to apply the principles of the mechanics of materials to the solution of general problems of engine design in such a way as to illustrate the procedure and simplify the work for specific cases. The author points out these principles and employs them in mathematical analysis so as to enable the novice to build up his judgment around them rather than around equations which were derived for particular cases and are worthless elsewhere. The book is confined to the proportioning of parts and omits the broader questions of accessibility, compactness, ease of production, and elegance.

METALLURGY OF IRON AND STEEL. By Bradley Stoughton. Third edition. McGraw-Hill Book Co., New York, 1923. Cloth, 6 × 9 in., 519 pp., illus., diagrams, tables, $4.

The last edition of this well-known textbook appeared in 1911. Since that time extensive changes have occurred in nearly every branch of practice, and knowledge of the inner nature of iron and steel has been greatly enlarged by metallography. These developments have made it necessary to rewrite the operating sections of this book and to revise the other portions. The amount of matter has increased, but the text has been kept within reasonable limits by omitting the chapter on physics and chemistry which appeared in earlier editions. The book is the only current American text covering the subject.

NOTES PRATIQUES SUR LES OUTILLAGES A DÉCOUPER ET A EMBOUTIR. By V. Ricordel. Dunod, Paris, 1923. Paper, 5 × 8 in., 126 pp., illus. 12 fr.

A practical handbook on the press working of metals, which treats especially of the dies, jigs, and fixtures used, and shows how these are applied to special problems of manufacture.

PERSONNEL MANAGEMENT. By Walter Dill Scott and Robert C. Clothier. A. W. Shaw Co., Chicago and New York, 1923. Cloth, 5 × 8 in., 643 pp., illus., diagrams, tables, $4.

The authors have attempted to outline the principles of personnel adjustment in industry as they are known today and to show how these principles may be used as a basis for creating and maintaining agencies for the adjustment of the individual to the work he is best qualified to do. Discusses such questions as the use of rating scales, tests of mental alertness and of special ability, and control charts. References accompany each chapter.

PREVENTION OF VIBRATION AND NOISE. By Alec. B. Eason. Henry Frowde, & Hodder & Stoughton, London, 1923. (Oxford Technical Publications.) Cloth, 6 × 9 in., 163 pp., illus., diagrams, 15s.

This book was compiled after the author had been collecting information upon methods of preventing vibrations caused by an unbalanced electric motor-generator from being a nuisance to inhabitants of the building in which it was situated. The object of the book is to relate facts which the author learnt and to indicate where fuller information concerning these facts may be found. In addition to the results of the personal experience of the author, it summarizes what others have written. The book discusses vibrations in buildings, bridges, towers and trains; isolating supports and damping devices; the transmission and isolation of sounds and noises; and machine balancing.

PROBLEMS IN INDUSTRIAL ACCOUNTING. By Thomas Henry Sanders. A. W. Shaw Co., New York and Chicago, 1923. Cloth, 6 × 9 in., 643 pp., $5.

This book aims to accomplish two things: to present a picture of the scope and variety of the problems that confront the executive and cost accountant; and to present sufficient illustrative material to show the standard practices of cost-accounting methods. Most of the problems have been collected by the Harvard Bureau of Business from the business concerns in which they arose, and are presented in their natural setting, with the actual facts stated. A number of bibliographies are included.

PROFITABLE MANAGEMENT. By J. Lee Nicholson. Ronald Press Co., New York, 1923. Cloth, 5 × 8 in., 117 pp., $1.25.

Mr. Nicholson presents a brief summary of the fundamentals of business control, written in a broad spirit and expressed simply, yet clearly. He hopes that the simplicity of the book may stimulate those engaged in management to broader constructive thought and action.

SMALL ELECTRIC MOTORS, D.C. AND A.C. By E. T. Painton. Isaac Pitman & Sons, London and New York, 1923. (Pitman's Technical Primers.) Cloth, 4 × 7 in., 120 pp., diagrams, 7 × 4 in., $0.85.

The fractional-horsepower motors used so widely for driving portable tools, piano players, washing machines and other domestic appliances, although they operate upon the same principles as larger machines, often differ widely from the latter in their operating characteristics. This little book aims to indicate the general characteristics of small motors, to point out departures from the characteristics of large machines and to set out the general principles govering their performance. The book is a welcome addition to the scanty literature on the subject. It should be of use to students and to users of small motors.

DIE STEUERUNGEN DER DAMPFMASCHINEN. By Heinrich Dubbel. Third edition. Julius Springer, Berlin, 1923. Boards, 6 × 9 in., 394 pp., diagrams, $2 40.

Treats of the theory and design of valve gears and reversing gears for reciprocating steam engines. The author confines himself almost entirely to types that meet the requirements of modern high-speed engines working under high pressures. The book is intended for designers. This edition omits some information on old and foreign types which appeared in earlier issues and contains a fuller treatment of reversing gears.

STRENGTH AND STRUCTURE OF STEEL AND OTHER METALS. By W. E. Dalby. Longmans, Green & Co., New York; Edward Arnold & Co., London, 1923. Cloth, 6 × 9 in., 176 pp., illus., diagrams, tables, $6.

The general purpose of this book is to compare methods of testing and to correlate the results by means of the load-tension diagram and to record the results of Professors Dalby's own researches on metals with instruments which he designed for recording accurately the load-extension, elastic extension and elastic torsion of metals. These instruments give information which formerly could be obtained only by a series of lengthy separate tests, with all the accuracy needful in practice.

Chapter one reviews the quality tests in use. Chapter two presents facts about the inner structure of the metals ordinarily used by engineers. Chapter three is devoted to the load-extension diagram and to the development by its aid of the law of similarity as applied to testing. Chapter four, on the inner structure of metals, summarizes the facts and principles of metallography. Chapter five brings together the results of research on the elastic properties of metals and discusses the looped elastic diagram. Chapter six gives the results of a research on the strength of screw threads.

STRENGTH OF MATERIALS. By Walter E. Wines. McGraw-Hill Book Co., New York, 1923. (Engineering Education Series.) Cloth, 6 × 9 in., 241 pp., illus., diagrams, $2.25.

This book, written primarily for the use of students of the Extension Division of the University of Wisconsin, is the outgrowth of the experiences of the Division in teaching this subject for a number of years. It is intended for use in such work and in vocational and shop schools as well as for those wishing to study without a teacher.

The subject-matter has been selected to meet the needs of both machine designers and structural designers and to form the foundation for advanced study. A particular effort has been made to have the text simple, clear, and explicit.

TREATISE ON ENGINE BALANCE USING EXPONENTIALS. By P. Cormac. E. P. Dutton & Co., New York, 1923. Cloth, 6 × 9 in., 151 pp., diagrams, tables, $8.

The introduction of exponentials, the author says, not only permits the discussion of ordinary topics of engine balance with remarkable ease but also makes it possible to examine the more complex types of aviation engines with little labor. The method also gives results of importance in the design of crank systems with specified balance. The book explains the method and applies it to symmetrical, offset, radial rotary- and oscillating-cylinder engines. Flywheel balance and the design of crank systems with a specified balance are also considered. An appendix gives the expansions in Fourier series of certain functions which arise out of the kinematics of the slider crank-chain mechanism.